NASA Conference Publication 3081

Space Transportation Avionics Technology Symposium

Volume 2—Conference Proceedings

Proceedings of a symposium held in
Williamsburg, Virginia
November 7–9, 1989

NASA

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NASA
National Aeronautics and
Space Administration
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Scientific and Technical
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SECTION 4

INTRODUCTION

The Space Transportation Avionics Technology Symposium (STATS) was held in Williamsburg, Virginia, November 7-9, 1990. This document (Volume II of NASA Conference Publication 3081) is a compilation of the materials presented at the symposium. It includes the agenda, an overview of the structure for technology panels and a collection of white papers and panel reports.

Section 1 contains statements of Avionics Technology "Needs" as presented by representatives from NASA programs during the plenary session on the first day.

Section 2 contains an overview of how the technology panels, which met in concurrent sessions, were structured and the introductory presentations which were presented during the plenary session on the first day.

Section 3 contains white papers prepared by the individual technology working groups that supported each symposium technology panel. These papers were prepared after the STATS so that the results of panel discussions could be incorporated into the text.

Section 4 contains the results and recommendations from each technology panel.

The STATS Executive Summary, NASA CP-3081 Volume 1, is a companion document and contains a description of symposium objectives, how the symposium was organized, a summary of attendees and their organizational affiliations, and a discussion along with conclusions and recommendations.

Revised 11/2/89

STATS SUBPANEL THEMES

FLIGHT ELEMENTS*

- C. KECKLER-LaRC
- P. SOLLOCK-JSC

ADV. AVIONICS SYS ARCHITECTURES
→ C. Meissner/LaRC, T. Barry/JSC
E. Elmore/LASC, J. Karas/GD
H. Poza/Sanders
M. Jeppson/Honeywell

ADVANCED PROCESSORS
→ J. Deyst/CSDL
H. Benz/LaRC
T. DeYoung/DARPA

INTEGRATED GPS/GN&C
→ A. Zeitlin/RIC, P. Saunders/JSC
J. Blucker/JSC, T. Barry/JSC
I. Hirsh/Boeing, M. Fernandez/Litton
H. Gelderloos/Honeywell

ADV. DISPLAYS & CONTROLS
→ J. Hatfield/LaRC
D. Villareal/JSC

ADV. COMM. & TELEMETRY
→ K. Land/JSC, R. Leonard/LeRC
M. Fitzmaurice/GSFC, D. Dalton/GSFC
S. Horan/NM State University

ADV. SENSORS & INSTRUMENTATION
→ R. Calloway/LaRC
R. Morrison/Rocketdyne

FAULT DETECTION & FAULT MGM'T
→ H. Lum/ARC
D. Lawler/JSC
J.T. Edge/JSC

ADV. ELEC. POWER, DIST, & CONTROL
→ H. Brandhorst/LeRC

EMA/POWER SYSTEMS
→ G. Sundburg/LeRC, J. Karas/GD
C. Cornelius/MSFC, B. Hoel/Honeywell
J.T. Edge/JSC

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C. Gott/JSC

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D. Ives/JSC

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A. Macina/IBM

TELEROBOTICS/TELEPRESCENCE
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M. Montemerlo/HQ, J. Lowrie/MMC
G. Reuter/JSC

AUTONOMOUS S/C CONTROL
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J. Lamoreux/JSC
B. Bullock/ISX

OPERATIONS MGM'T SYSTEM
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M. Hanson/JSC
R. Lee/TRW

ADV. TEST C/O SYSTEM
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J. Tully/LSOC
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A. Blackburn/Mitre
R. Hartenstein/JSC

ADV. SOFTWARE INTEGRATION
→ J. Garman/JSC

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D. Long/JSC

HEALTH STATUS & MONITORING
→ J. Baker/Pratt, A. Brewer/JSC
T. Barry/JSC, L. Uljoh/JSC
J. Albert/Boeing, A. Norman/Rocketdyne
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- CAPT. A. NGUYEN-ALS /JPO

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→ D. Dyer/NASA Reston
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→ H.E. Smith/LESC, B. Buchbinder/Hq.
W.G. Bates/JSC
J.T. Edge/JSC

TOTAL QUALITY MANAGEMENT
→ K. Shipe/MMC
R. Sapp/Lockheed
M. Lofton/MDSSC

LOW COST AVIONICS
→ W. Brantley/MSFC, L. Kinports/Honeywell
K. Land/JSC
F. Kuenzel/GD

COST ESTIMATION & BENEFITS
→ J. Hamaker/MSFC, B. Boehm/UCLA
E. Dean/LaRC, E. Fridge/JSC
K. Cyr/JSC

COMPUTER AIDED S/W ENGINEERING
→ C. Walker/LaRC
G. Raines/JSC

COMPUTER SYSTEMS & S/W SAFETY
→ C. McKay/UHCL
G. Finelli/LaRC
A. Patterson-Hine/ARC

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→ T. Barry/JSC, L. Small/IBM
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R. Monis/Harris Corp.

ADV. AVIONICS LABORATORIES
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C. Simmons/MDSSC, L. Shockley/RIC
D. Johnson/Boeing, TBD/Lockheed

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→ P. Schoen/Rockwell
TBD/Honeywell
D. Hudson/MMC
D. Deets/DFRC

Kim Ulrich*

→ Technology Topic Spokesperson
* Panel Rapporteur

Space Transportation Avionics Technology Symposium
Wyndham Hotel - Williamsburg, Virginia
November 7-9, 1989

AGENDA

Monday Evening

7:00-9:00pm	Registration at Hospitality Suite, Rooms 220 & 222 -Badge, Agenda, Preprints, Banquet Tickets and Visitor Information Package	

Tuesday

7:30am	Registration/Continental Breakfast; Westminster Ballroom Foyer	
8:00-9:00am	Opening Remarks	
	-Call to Order	General Chairman
	-Welcome	R. Hook
	-Keynote Speaker	J. R. Thompson
9:00-9:30am	Symposium Overview	
	-Code MD	D. Branscome
	-Code RC	J. DiBattista
	-General Chairman's Comments	K. Cox
9:30-Noon	Summaries of User Technology Needs (45 min. each)	
	-STS	D. Winterhalter/ Code ME
	-NMTS to LEO & Return	H. Erwin/JSC
	-Cargo Systems & ELV's To LEO/Return	G. Austin/MSFC
	-Commercial ELV avionics	Martin Marietta McDonnell-Douglas General Dynamics
12:00-1:00pm	Lunch; Westminster Ballroom Foyer	
1:00-3:30pm	Summaries of User Technology Needs (30 min. each)	
	-LEO Facility	A. Edwards/Code S
	-People Return	H. D. Myers/JSC
	-On-Orbit Transportation	F. Huffaker/MSFC
	-Exploration	I. Bekey/Code Z
	-Reliability and Quality	D. Barney/Code Q
3:30-5:30pm	Symposium Subpanel Overviews (30 min. each)	
	-Flight Elements	C. Keckler/LaRC P. Sollock/JSC
	-Operational Efficiency	T. Davis/KSC D. Bland/JSC
	-Payload Accomodation	S. Cristofano/Code M A. Nguyen/ALS-JPO
	-SE&I	E. Chevers/JSC A. Haley/MSFC

Space Transportation Avionics Technology Symposium
Wyndham Hotel - Williamsburg, Virginia
November 7-9, 1989

AGENDA (Continued)

Wednesday

7:15am	Continental Breakfast; Williamsburg Foyer and Westminster Ballroom Foyer	
7:45-8:30am	Joint Session Flight Elements & SE&I Panels: Risk Management of Large Electronic Systems at DARPA	Col D. Dougherty
8:30-8:45am	Subpanels Convene - Discuss and define process	Subpanel meetings
8:45-12:30pm	Review of specific technologies	Subpanel meetings
12:30-1:30pm	Lunch; Westminster Ballroom Foyer (Box Lunch)	
1:30-2:30pm	Continued review of specific technologies	Subpanel meetings
2:30-3:00pm	Break	
3:00-4:00pm	Additional Technical Topics	Subpanel meetings
4:00-5:00pm	Session Products - Review of "Holes" - Facility Requirements - Cultural Change Identification	Subpanel meetings
7:00-7:30pm	Reception/Cash Bar	
7:30-9:00pm	Colonial dinner with "light" entertainment	
9:00-10:00pm	Splinter meetings as required	

Thursday

8:00am	Continental Breakfast; Williamsburg Foyer and Westminster Ballroom Foyer	
8:30-12:30pm	Assessment of technology maturity vs. needs - Preparation of panel summary	Subpanel meetings
12.30-1:30pm	Lunch; Colony Room	
1:30-3:30pm	Subpanel presentation of findings (30 min. each) - Each Technology Subpanel Chairperson	Plenary Session
3:30-4:30pm	Open Forum Discussions - Questions from the floor	General Chairman/All
4:30-5:00pm	Conclusions and Recommendations	Code MD/RC
5:00-5:30pm	Symposium Wrapup	General Chairman

Section 1

USER "NEEDS" PRESENTATIONS

NATIONAL SPACE TRANSPORTATION SYSTEM (NSTS)

708

530310

148

N91-17021

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM

WILLIAMSBURG, VIRGINIA
NOVEMBER 7 - 9, 1989

NATIONAL SPACE TRANSPORTATION SYSTEM (NSTS) TECHNOLOGY NEEDS

WHITE PAPER

NASA, OFFICE OF SPACE FLIGHT
WASHINGTON, D.C.

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ABSTRACT

SHUTTLE AVIONICS NEEDS

The National Space Transportation System (NSTS) is one of the Nation's most valuable resources, providing manned transportation to and from Space in support of payloads and scientific research. The NSTS program is currently faced with the problem of hardware obsolescence, which could result in unacceptable schedule and cost impacts to the flight program. Obsolescence problems occur because certain components are no longer being manufactured or repair turnaround time is excessive. In order to achieve a long-term, reliable transportation system that can support manned access to space through 2010 and beyond, NASA must develop a strategic plan for a phased implementation of enhancements which will satisfy this long-term goal.

The NSTS program has initiated the Assured Shuttle Availability (ASA) project with the following objectives: eliminate hardware obsolescence in critical areas, increase reliability and safety of the vehicle, decrease operational costs and turnaround time, and improve operational capability. This project in part will insure the development of an evolved Space Shuttle which will be the primary implementation vehicle for advanced technologies for the next 30 years.

The Shuttle avionics system, which controls most of the flight critical subsystems, is a primary candidate for upgrades and enhancements. The development of enhanced avionics is a critical step in the ASA process and certain goals must be addressed early in the program to obtain the most efficient and low cost design. This phased implementation plan can be broken into four phases spanning over a 32-year period. Phase I (1984-1991) will complete the design and incorporate the upgrade programs that have already been funded through the NSTS program. Phase II (1992-1997) will incorporate upgrades mandatory to keep the system on-line and functional (obsolescence changes and safety critical changes). Where budget allows, non-mandatory upgrades that will improve operational turnaround and performance will be considered. Phase III (1998-2007) will scope the total NSTS needs and be targeted to accommodate new missions (Lunar Base, Mars, Advanced Launch Systems, etc.). Phase IV (2008-2016) will primarily concentrate on keeping the Shuttle operational by replacing obsolete components. The Shuttle will be approaching lifetime limitations near the end of Phase IV; therefore, further advanced technology should be funded under other programs, such as MARS, Next Manned Transportation System (NMTS), etc.

It is imperative that future vehicles (NMTS, Shuttle C, etc.) be considered in the design of any new system. These programs must benefit from the new technology development incorporated into the Shuttle. There is also a potential reciprocal situation where a planned NSTS upgrade is based on a "pathfinder" activity in another program. Some high level goals that will be addressed are as follows: 1) determine long-term effects of new enhancements throughout the ASA process, 2) consider hardware and interface commonality with other programs where applicable (i.e., Space Station, Shuttle C, Crew Escape and Rescue Vehicle, Orbiter Maneuvering Vehicle, etc.), and 3) capitalize on new technology development (autonomous systems) to reduce labor intensive operational procedures that currently exist.

In summary, the strategy for ASA will be to first meet our mandatory needs--keep the Shuttle flying. Non-mandatory changes that will improve operational capability and enhance performance will then be considered if funding is adequate. Upgrade packages should be developed to install within designated inspection periods, grouped in a systematic approach to reduce cost and schedule impacts, and allow the capability to provide a Block II Shuttle (Phase III).

INTRODUCTION

This paper addresses a preliminary plan to meet near and long-term avionic needs of the Shuttle Orbiter program. Since the Shuttle is the only operational manned vehicle, it will be the vehicle for implementing advanced technology development. Long-term goals, such as advanced expendable launch systems (i.e., Shuttle C) and the NMTS will be a design consideration for new systems during the Shuttle life cycle. The ASA program will provide the necessary improvements to keep the vehicle operational through its life cycle, which is estimated to be through the year 2020. However, there is a point where advanced technology is no longer relevant to the ASA program and will fall under other designated programs such as the Lunar Base, Mars, NMTS, etc. New facilities required to develop or verify new design concepts, such as development avionics laboratories, will be funded through the institutions budget or the specific programs that need this new technology.

Also, Shuttle needs in terms of ASA will be addressed. New technology development that can be utilized for Mars missions or the NMTS will be discussed in broad terms, not directly under the ASA program. Although orbiter avionics upgrades are critical, they will be in competition with other systems, such as Solid Rocket Boosters (SRB) and Space Shuttle Main Engines (SSME). The NSTS program may not be able to incorporate all changes that are beneficial, however, those that are affordable and offer the correct long-term benefits will be implemented. It should be noted that the ASA program is a contender for funding, but, has not officially been approved in the budget process. Other methods of funding may have to be considered.

AVIONICS SYSTEM OVERVIEW - LIMITATIONS AND CONSTRAINTS

The Space Shuttle avionics system plays an integral role in all phases of flight from pre-launch to post landing. This highly complex system is composed of over 300 Line Replaceable Units (LRU'S) connected to five General Purpose Computers (GPC) through a digital data bus network. The primary functions of the system are to provide ground checkout, performance monitoring, and control of the vehicle. The system architecture, through use of redundant hardware and complex software programs, allows for failures (fail-operational/fail-safe) without compromising the safety of the vehicle. The design and development of this vehicle took place during the 1970's; therefore, the capabilities designed into this system were significantly advanced compared to other systems utilized during this timeframe.

The avionics system interfaces with almost every subsystem on the vehicle; External Tank (ET), SRB's, SSME's, Flight Control, etc. Most functions such as guidance, navigation and control of the vehicle, communication and tracking, payload operations, vehicle attitude control, subsystem monitoring, and failure annunciation are performed by the Data Processing System (DPS). The DPS hardware composition and functions are shown in Table 1.

TABLE 1.

DATA PROCESSING SYSTEM

HARDWARE	***FUNCTION***	***UNITS***
General Purpose Computers	Central Processing	5
Digital Data Buses	Transmit Input/Output Commands	24
Mass Memory Units	Software and Data Storage	2
Multiplexer Demultiplexer (19 ORB, 4 SRB)	Convert and Format Data	23
Main Engine Interface Unit	Command SSME's	3
Multifunction CRT Display System	Monitor and Control Vehicle	4
Master Events Controller	Command signals to arm and safe pyrotechnics	2
Master Timing Unit	Provides precise frequency output for timing and synchronization	1

The DPS software is a sophisticated set of programs, which utilizes over 500,000 lines of code. These programs were developed using a combination of a specialized high-order language and assembly language to accommodate real-time space flight applications. The Primary Avionics Software System (PASS) is the principal software used to operate the vehicle. An independently coded backup software package is loaded into the fifth GPC and is mainly utilized if a generic failure causes PASS to become inoperative.

During ascent and entry phases of flight, the DPS is configured into four independent strings (two-fault tolerant) in a synchronized fashion, each string utilizing one GPC.

Redundancy is managed in both the software and hardware making this system stable and reliable. The Shuttle avionics system is one of the most sophisticated and integrated aerospace systems today. The Shuttle avionics architecture can be seen in Figure 1.

As with any complex system, the Shuttle avionics system has limitations. One of the primary limitations with the current system is the labor intensive requirement for flight operational readiness (i.e., software/hardware verification, I-Load verification, etc.). Also, highly complex designs for certain components necessitate a highly skilled person for repair and maintenance (long turnaround time). These limitations and others require certain upgrades to the ground and flight hardware to improve turnaround time and guarantee the flight manifest is met. As R&D laboratories invent new and more efficient electronic components, the avionics systems which are in use today become obsolete and parts are no longer manufactured.

While designing new LRU's to eliminate obsolescence, the opportunity exits to increase performance capabilities on the Shuttle program. However, this creates a paradox. The significant amount of time required to design, develop ("tailor" for specific requirements), and qualify a piece of hardware along with new technology development, causes a system to be obsolete before it is ever flown. These constraints and realities must be considered in new avionics systems designs during the ASA Program.

ASSURED SHUTTLE AVAILABILITY

The ASA program will be a phased implementation plan of enhancements to the vehicle with the following objectives in mind: eliminate hardware obsolescence in critical areas, increase reliability and safety of the vehicle, decrease operational costs and turnaround time, and improve operational/payload capability. This phased implementation can be broken down into four phases spanning over a 32-year period.

Phase I (1984-1991) will complete the design and incorporate the upgrade programs that have already been funded through the NSTS program. Additionally, budget has been requested to start new upgrades in fiscal year 1991. The current programs include the enhanced GPC, Inertial Measurement Unit (IMU), MDM, Star Tracker, Tacan, Mass Memory Unit (MMU), and the Master Events Controller (MEC). The major drivers behind these upgrade programs were obsolescence and maintainability (repair costs and turnaround time). Most of these enhancements will reduce weight, volume, power, and take advantage of new available technologies

SHUTTLE AVIONICS ARCHITECTURE: A HARDWARE-SOFTWARE CORE WITH PERIPHERAL HARDWARE

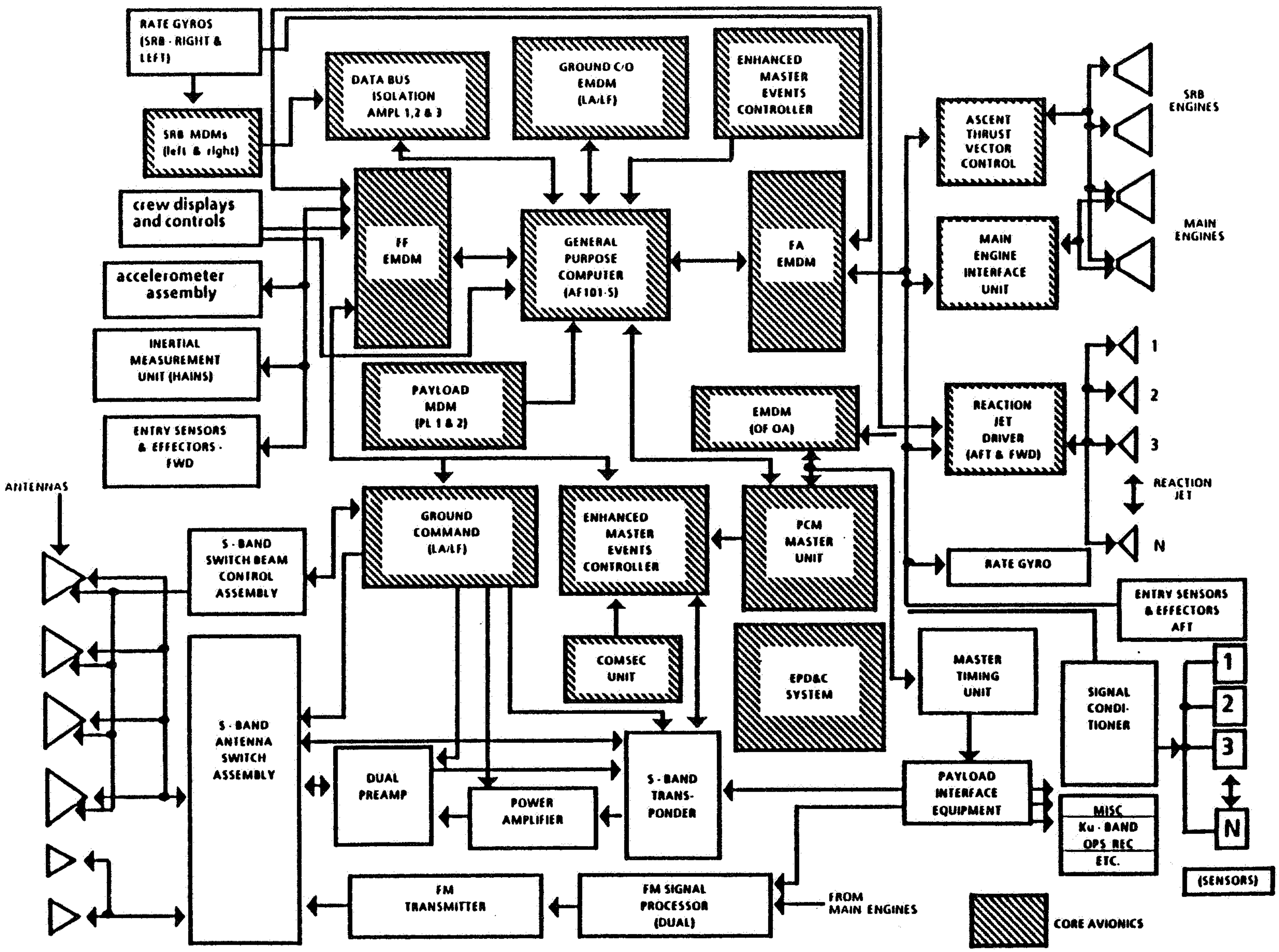

Figure 1

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to improve reliability and maintainability, thus, reducing the life cycle costs of the hardware. Additionally, enhancements to the new GPC's include increased memory capability and faster data processing. The new IMU's were enhanced with a better error detection capability reducing turnaround and software verification. Upgrades that are functionally "transparent" and require little or no changes to the software, such as the IMU and MDM, are attractive because of reduced program costs. Phase I will be completed by the end of 1991 when OV-105 becomes operational and significant work begins on items for Phase II of the implementation process.

Phase II (1992-1997) of the implementation process is very important relative to the designs chosen for new systems. The major upgrades that will be incorporated in this phase are those mandatory to keep the system on-line and functional (obsolescence changes and safety critical single-point failures). Other enhancements that may fall into this phase are those driven by economical factors (reduced life cycle costs) and desirable changes (non-mandatory performance improvements).

As in all programs, the project funding levels will require all potential candidate upgrades to be cost effective and beneficial to the overall NASA Agency, whether for obsolescence upgrades or operational improvements. The current redundancy and fail operational/fail safe features must be maintained with any new upgrade. Although the NSTS program should be cost effective, we must keep in mind that the NSTS's role is to be the implementation vehicle for new technology developments that make sense to implement. Likewise, the NSTS should not implement new technology that is not cost effective. To insure we are in step with the R&D programs, we should work closely with the Office of Aeronautics and Space Technology.

The proposed changes for Phase II presently being contemplated that are necessary because of obsolescence or will provide more capability are as follows: glass cockpit, electrical power distribution and control (EPD&C), Integrated Navigation System/Global Positioning System (INS/GPS), and integrated communications system. Some of these features will not only eliminate obsolescence, but will improve reliability and consolidate (reduce) the number of LRU's. These systems will also decrease weight and power, improve the performance of the vehicle, and lessen ground testing requirements substantially. Although obsolescence can be solved without incorporating integrated systems, integration will be advantageous and cost effective to the program in terms of reliability, performance, and ground turnaround. The architecture of these systems changes will be designed to accommodate a Block II Shuttle (Phase III) without a total system redesign. A Block II Shuttle concept will

incorporate numerous enhancements that require significant modifications to the vehicle during an extended vehicle downtime and can only be accomplished with a fifth Orbiter sustaining 14 flights per year. Some candidates may require flight tests (INS/GPS) to assess the reliability of the system. These tests, whether ground or flight, will be identified and costed during the trade studies.

Non-mandatory upgrades that will improve operational turnaround and performance (weight savings, automated systems, etc.), generally require major mods to the vehicle or significant up-front funding. Some of the options that fall into this category are as follows: on-board verification and checkout, high power fuel cells, electromechanical actuators, automated flight design system, integrated flight status monitoring system, etc. If these upgrades are considered, it is imperative that comprehensive trade studies be made before significant funding is committed. More autonomous systems will eliminate the labor intensive requirements for flight readiness; however, limited funding will necessitate that all changes be compared on the basis of performance enhancements and safety improvements. Although non-mandatory changes are potential candidates for Phase II, budget constraints could push these options into Phase III.

The selection of Phase II upgrades must be given serious engineering forethought so the program does not get locked into the same labor intensive operational costs and turnaround time that exist today. Additionally, the Agency's credibility in costing projects is of great concern; therefore, a well thoughtout contractor proposal will be negotiated prior to Authority to Proceed (ATP). Planned NSTS upgrades could also be based on "pathfinder" activities in other programs, thus reducing costs. Commonality of hardware, system interfaces, software, and crew procedures should be considered where applicable in Phase II upgrades. For example, commonality will reduce manufacturing and testing costs.

Other factors relevant to mandatory and non-mandatory changes are structural and modification downtime. Upgrades will be selected and scheduled so that the flight manifest is not impacted. Flying with differently configured vehicles (hardware and software) is not cost effective in terms of crew training, facility upgrades, etc. Some configuration differences will be unavoidable; however, they can be drastically reduced if upgrades are grouped systematically or functionally with transparency to other areas. Costs can also be reduced if enhancements are made in interrelated groups such as glass cockpit, automated cockpit switches and controls, on-board crew training, on-board checkout and verification, assured orbiter return (crew unable to perform time-critical functions), health monitoring system, etc.

Costs for facility upgrades to the Shuttle Avionics Integration Laboratory (SAIL), Shuttle Mission Simulator (SMS), Mission Control Center (MCC), etc., will be considered when selecting enhancements. Upgrades in Phase II will be installed in OV-106 (assuming approval) in-line. Approval of OV-106 will allow modification periods in excess of three months after OV-106 is operational. The orbiter modification schedule is represented graphically in Figure 2.

The priorities for Phase II are to first implement mandatory changes (obsolescence and safety). If schedule and budget funds allow, examples of non-mandatory candidates that will be considered are automated flight design, on-board checkout and verification, and electromechanical actuators. Automated flight design and on-board checkout/verification will both reduce manpower requirements for flight readiness, thus fulfilling a highly desirable goal. Electromechanical actuators will improve reliability, turnaround time, performance, fault tolerance, as well as decrease weight and costs. In reality, changes such as high power fuel cells, electromechanical actuators, advanced EPD&C, and on-board checkout and verification will most likely be implemented in Phase III because of the required modification time.

Phase III (1998-2007) will scope the total NSTS needs and be targeted to accommodate new missions (Lunar Base, Mars, etc.). Additionally, some of the upgrades incorporated in Phase I will already be obsolete and require further redesign. Rather than upgrade specific LRU's, new advanced architectures should be considered for 1) evolving into a Block II Shuttle concept, and 2) be implemented in line to a new orbiter (i.e., OV-107). Any projects not funded in Phase II will have top priority.

Approval of a new vehicle (OV-106) will play a key part in the implementation of any upgrades requiring major modifications. Without a fourth vehicle, upgrades must be incorporated during the normal KSC flow and/or the planned 3-month structural inspection period in order to maintain the flight manifest. This could seriously reduce any major modifications made to the vehicle or upgrades will have to be implemented incrementally. If OV-106 is approved, this will allow individual vehicles to be scheduled for long periods of downtime to install major modifications.

The main objectives of Phase III are to progress into a more autonomous operational program and utilize previous upgrades and new technologies to develop a Shuttle Block II concept. In terms of ground processing, automation of a bad process is not necessarily good. The process must be analyzed for efficiency and possibly changed before it is automated. The advanced technology developed in Phase III will be geared toward requirements for the NMTS and mission requirements for Mars.

SHUTTLE PHASED IMPLEMENTATION PLAN

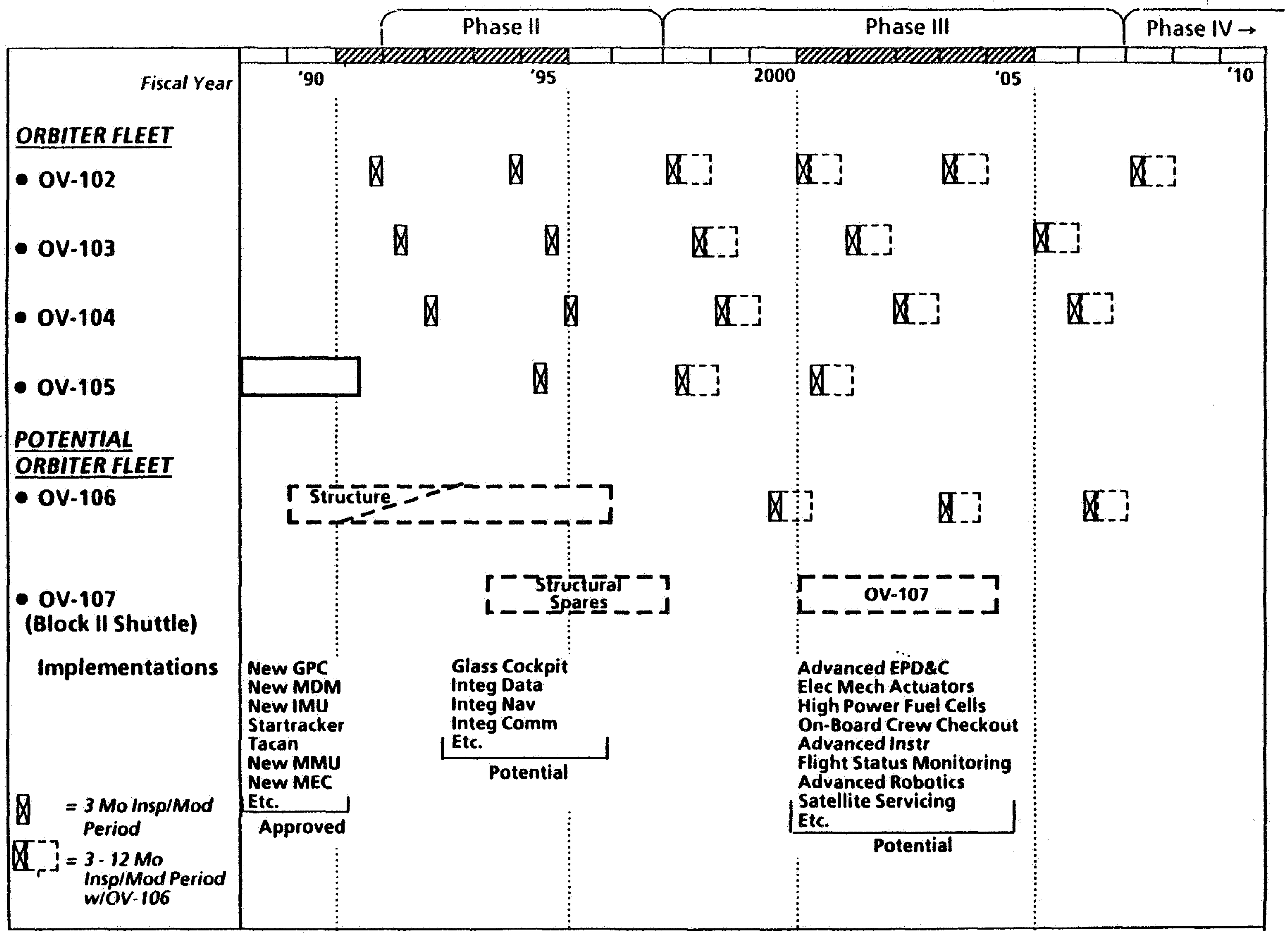

Figure 2

The autonomous systems in avionics such as rendezvous and docking, landing, and GN&C can be applied to the Mars program and advanced expendable launch vehicle (ELV) programs.

If a Block II Shuttle (OV-107) were initiated in 1998, studies for advanced avionics architectures must begin in 1995. This would allow five years for DDT&E before the hardware is installed (2001). Evolving into a Block II Shuttle will allow more capability to be designed into the avionics system. Upgrades will not require transparency to the existing architectures, such as those implemented in Phase II. Figure 2 graphically represents a potential plan for a future Orbiter fleet.

Potential candidates for this phase are as follows: advanced avionics laboratory (integrated Shuttle/Space Station), advanced avionics architecture (facilitate vehicle autonomy), satellite servicing (autonomous rendezvous, docking, etc.), advanced robotics (autonomous payload deployment). To obtain these sophisticated systems, investment in risk analysis and management systems (identify risks inherent in new avionics designs) and computer aided software engineering (artificial intelligence) will be required.

The integrated avionics laboratory is applicable to ASA and should be implemented early in this phase (1998) with trade studies performed in 1996/1997. This facility will combine the SAIL with the Multisystem Integration Facility (MSIF) for Space Station. This concept will reduce overall integration costs for space transportation systems and maximize use of center expertise for subsystem development and verification. It will also promote commonality of hardware between the two programs.

New facilities that are required for design and verification of new approved flight hardware/software systems (i.e., advanced architectures) will be provided through institutional funds. Such facilities could include a Data Management Systems Test Bed, Optical Avionics Laboratory, Systems Integration Laboratory, etc.

The Risk Analysis and Management System is another high priority candidate that should be initiated early in Phase III. This system can be utilized to identify and quantify risks associated with new avionics architectures in order to make cost effective, reliable, and safe upgrades.

Phase IV (2008-2016) will primarily concentrate on keeping the Shuttle operational (i.e., replace obsolete components from Phase II, minor upgrades). The Shuttle will be approaching lifetime limitations near the end of this phase; therefore, further advanced technology should be funded under other programs such as Mars, NMTS, or Advanced Launch Systems (ALS).

SUMMARY

The strategy for ASA will be to first meet our mandatory needs--keep the Shuttle flying. This requires that all upgrades due to obsolescence and safety have first priority. Non-mandatory changes to improve operational capability and turnaround will be incorporated when program funding can accommodate these upgrades.

The primary goals for ASA are as follows: eliminate obsolescence, reduce operational costs and turnaround time without impacting safety and reliability, increase performance, and enhance operational capability. Selection of new enhancements will be made based on cost and performance benefits. Limited funding will require that significant trade studies be made to determine the appropriate enhancements to implement, accurately negotiate costs, and understand the operational benefits/savings.

Upgrade packages should be developed to install within designated inspection periods, grouped in a systematic approach to reduce cost and schedule impacts, and allow the capability to provide a Block II Shuttle. Approval of follow-on orbiters is critical to allow sufficient time for major modifications. Commonality of hardware, software, crew procedures, and system interfaces between various programs, where applicable, is highly desirable.

The program should eventually evolve to a more autonomus operational concept eliminating costs and turnaround time wherever possible. NASA intends to retain its role as the leader of new technology development, and the Shuttle is a good base for implementing technology improvements.

It should be noted that avionics upgrades, although critical, will be in competition with other systems such as SRB's and SSME's. The NSTS program may not be able to incorporate all changes that are beneficial, however, those that are affordable and offer the correct long-term benefit will be implemented. Although the ASA program is supported by the Agency, it has not been officially approved in the budget process.

709

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PRESENTATION 1.2

N91-17022

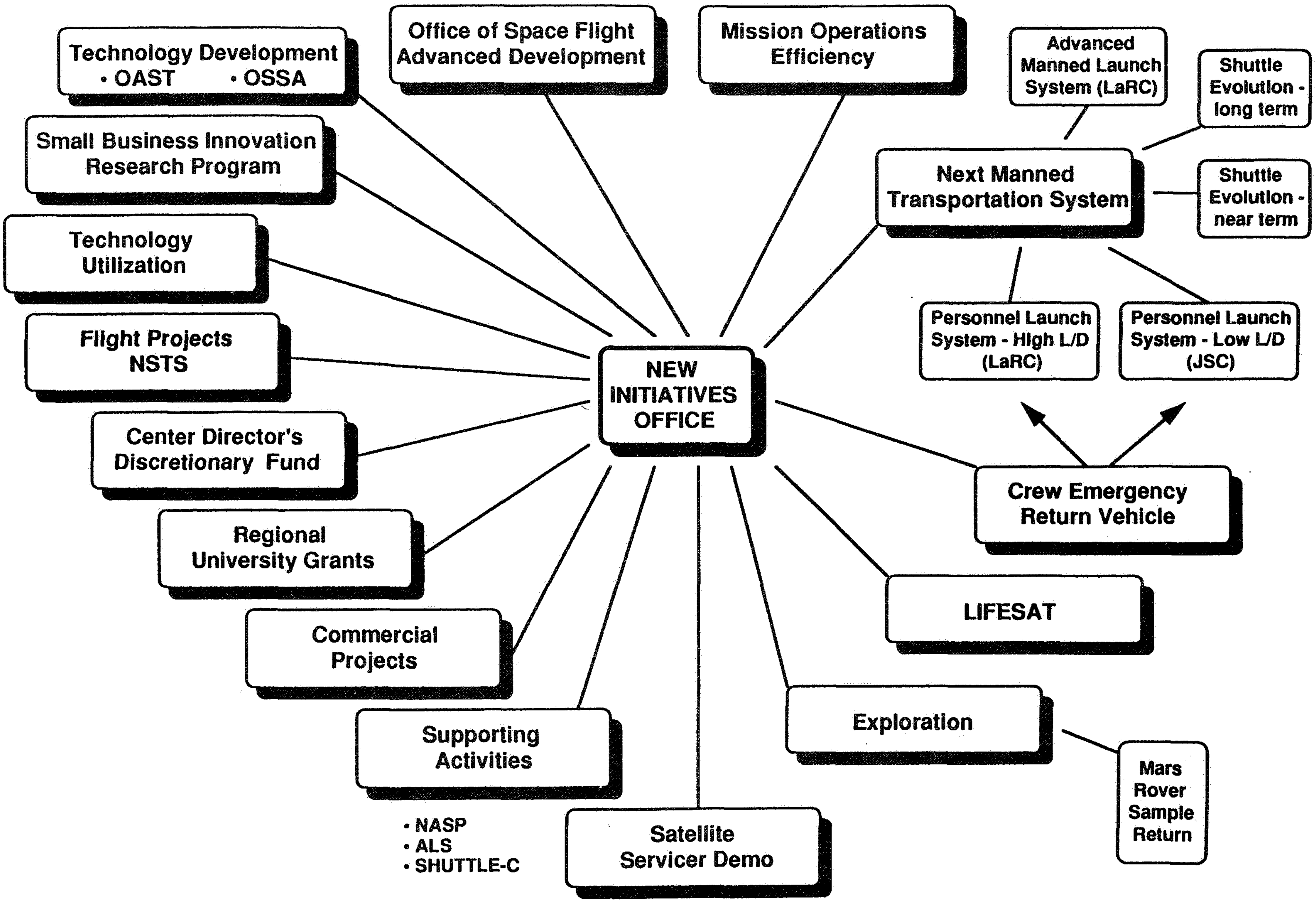
NEXT MANNED TRANSPORTATION SYSTEM

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM

NEXT MANNED TRANSPORTATION SYSTEM

Harry Erwin
New Initiatives Office
Johnson Space Center

JSC's NEW INITIATIVES



NEXT MANNED TRANSPORTATION SYSTEM

What are Avionics?

Avionics are the connecting link that integrate the hardware and software which satisfy system requirements.

- Systems analysis and engineering required
- Requires detailed knowledge and definition of non-avionics subsystems
- Allows verification of flight readiness

Avionics are both a part of *each* flight system and a process for integration.

NASA

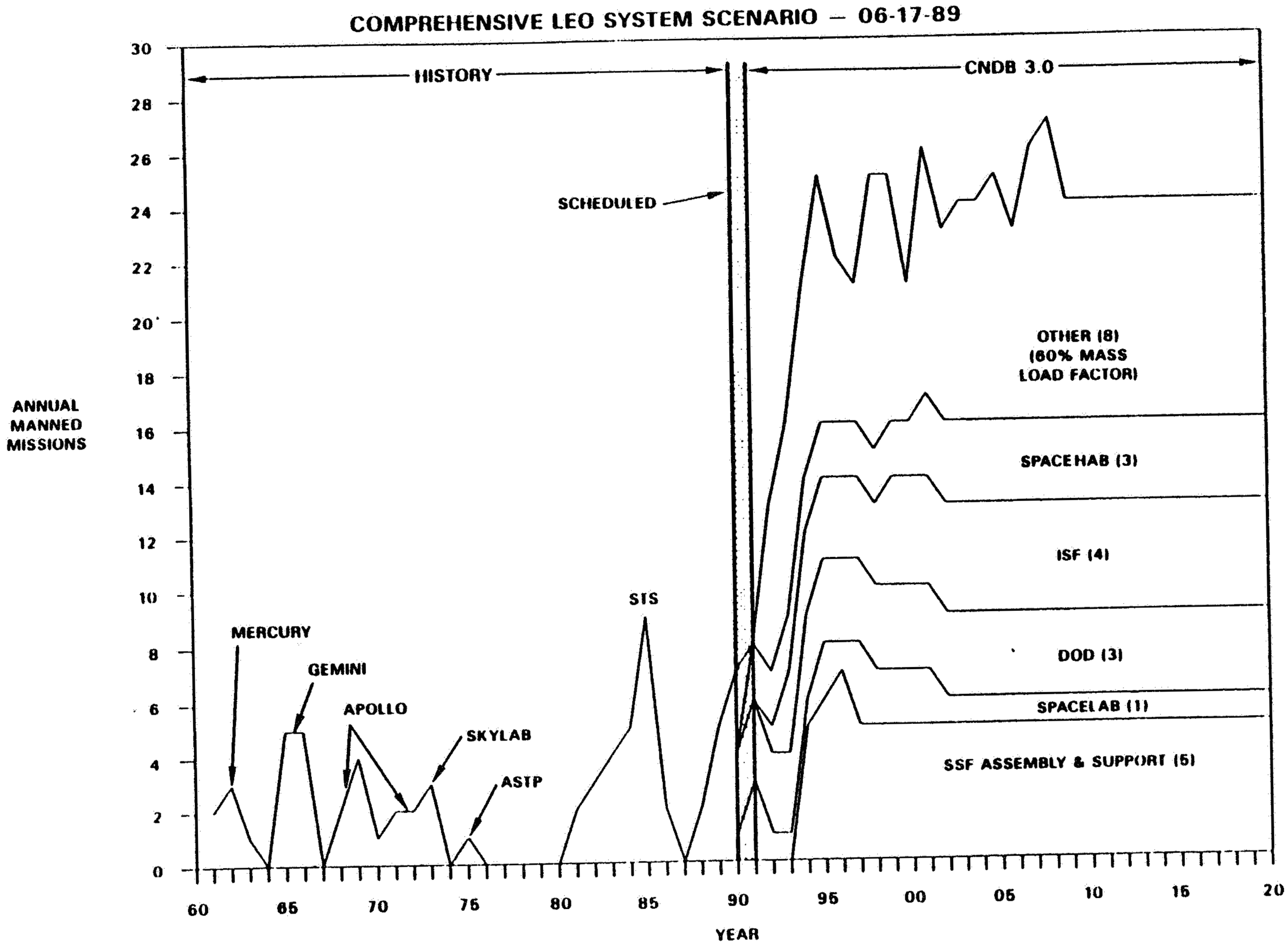
NEXT MANNED TRANSPORTATION SYSTEM

Top-Level Considerations

- Assured manned access to space
- First-stage abort
- Lower cost of ownership

NASA

NEXT MANNED TRANSPORTATION SYSTEM



NASA

NEXT MANNED TRANSPORTATION SYSTEM

Issues

- Systems which transport people only
- Launch escape
- Down cargo
  - Blunt body reentry
  - Tethers (for trash)
  - Continuing shuttle-like capability
- Solid vs. liquid propulsion
- Systems integration of NASA programs
  - Manage programs - not projects

NASA

NEXT MANNED TRANSPORTATION SYSTEM

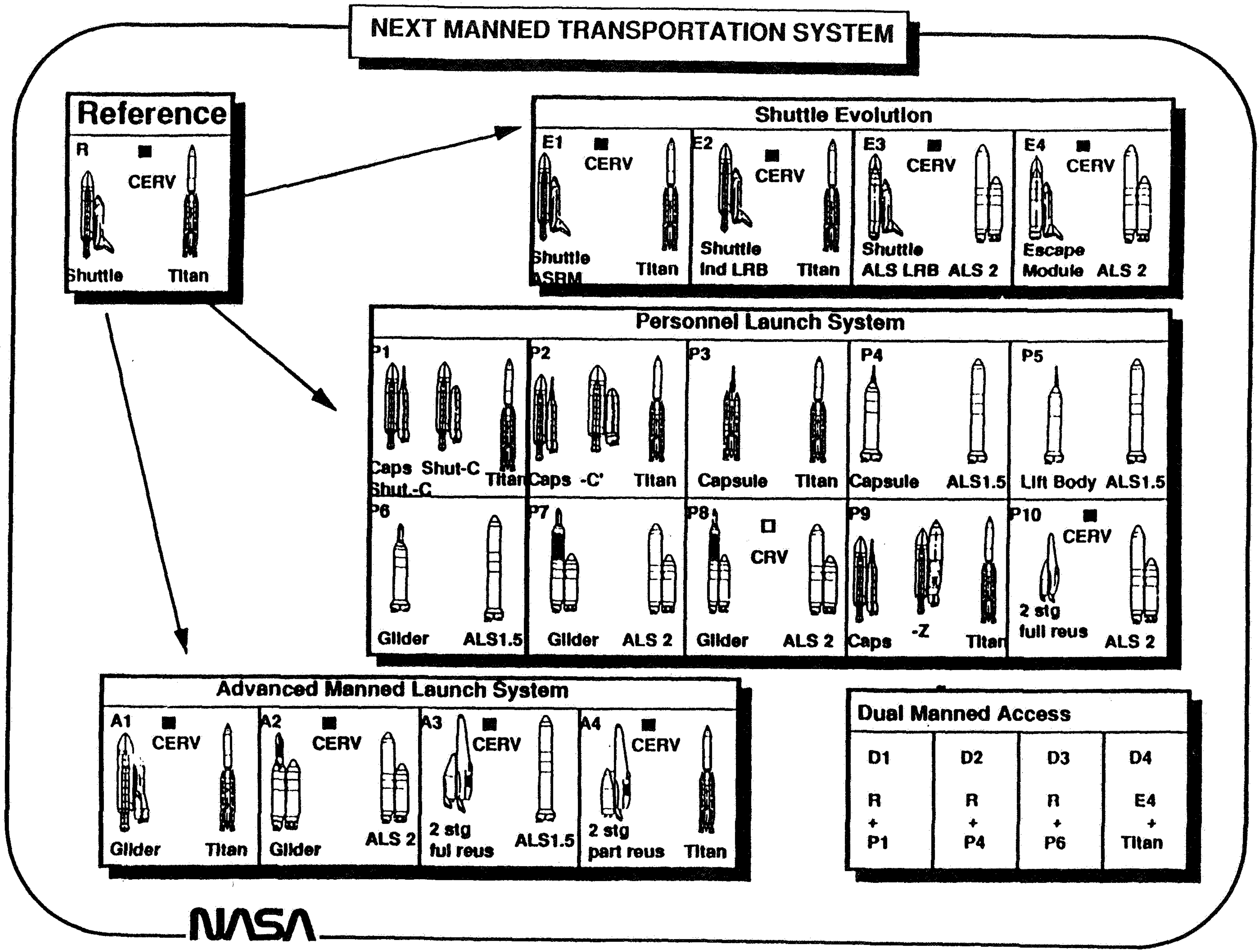
Goals

- Satisfy people/payload requirements
- Improve cost effectiveness
- Increase reliability
- Increase margins

Paths Studied to Meet Goals

- STS evolution
- Personnel launch system
- Advanced manned launch system

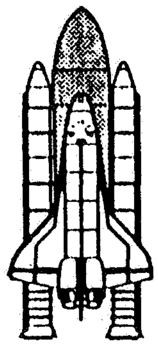
NASA


NEXT MANNED TRANSPORTATION SYSTEM
Reference
R CERV
Shuttle Titan
Shuttle Evolution
E1 CERV
Shuttle ASRM Titan
E2 CERV
Shuttle Ind LRB Titan
E3 CERV
Shuttle ALS LRB ALS 2
E4 CERV
Escape Module ALS 2
Personnel Launch System
P1
Caps Shut-C Shut-C Titan
P2
Caps -C' Titan
P3
Capsule Titan
P4
Capsule ALS1.5
P5
Lift Body ALS1.5
P6
Glider ALS1.5
P7
Glider ALS 2
P8 CRV
Glider ALS 2
P9
Caps -Z Titan
P10 CERV
2 stg full reus ALS 2
Advanced Manned Launch System
A1 CERV
Glider Titan
A2 CERV
Glider ALS 2
A3 CERV
2 stg ful reus ALS1.5
A4 CERV
2 stg part reus Titan
Dual Manned Access
D1 R + P1
D2 R + P4
D3 R + P6
D4 E4 + Titan
NASA

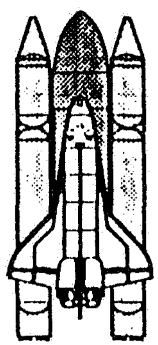
NEXT MANNED TRANSPORTATION SYSTEM

NMTS Candidate Concepts

Shuttle Evolution

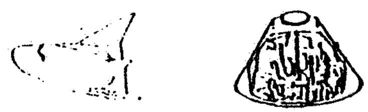


Current STS

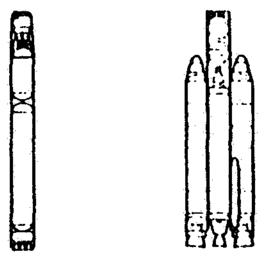


Evolved STS

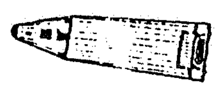
Personnel Launch System (PLS)



Crew Modules

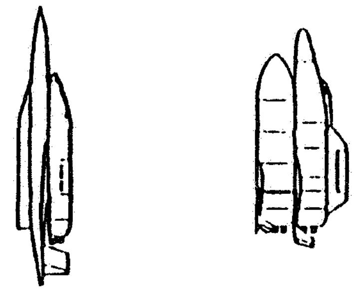


Launch Vehicles

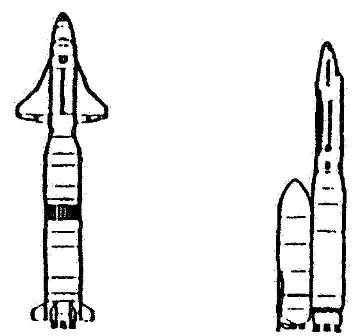


Cargo Return Vehicle

Advanced Manned Launch System (AMLS)



Fully Reusable



Partially Reusable

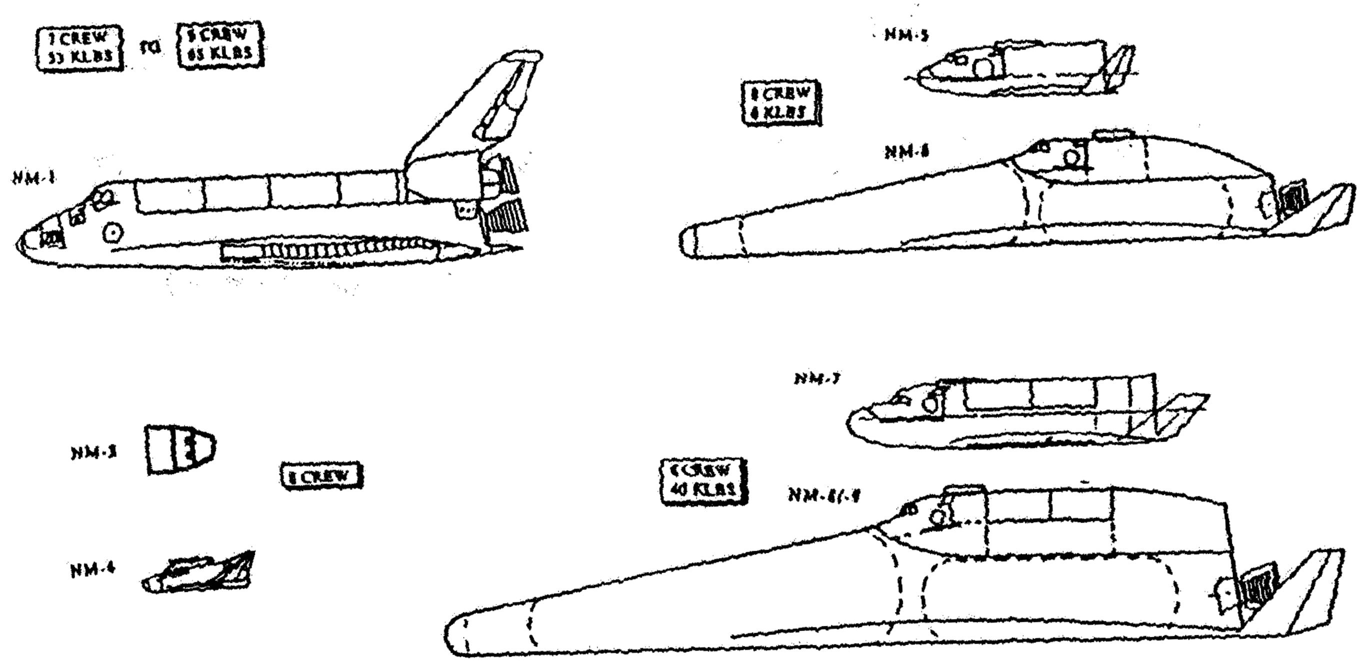
NASA

NEXT MANNED TRANSPORTATION SYSTEM

Next Manned Options

NM-1 Current Orbiter
NM-2 Improved Orbiter (crew escape capsule)
NM-3 Ballistic (low L/D Capsule - PLV)
NM-4 Lifting Body (PLV)
NM-5 Glider (PLV)

NM-6 Fully Reusable 2 Stage (PLV)
NM-7 Large Glider (AMLS)
NM-8 Fully Reusable 2 Stage (AMLS)
NM-9 Partly Reusable 2 Stage (AMLS)
NM-10 Ballistic (Low L/D) CERV



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NEXT MANNED TRANSPORTATION SYSTEM

STS Evolution

- Exploit new technologies
- Build on existing engineering data base
- Minimize mold-line/configuration changes
- Counter obsolescence
- Increase people carrying capability

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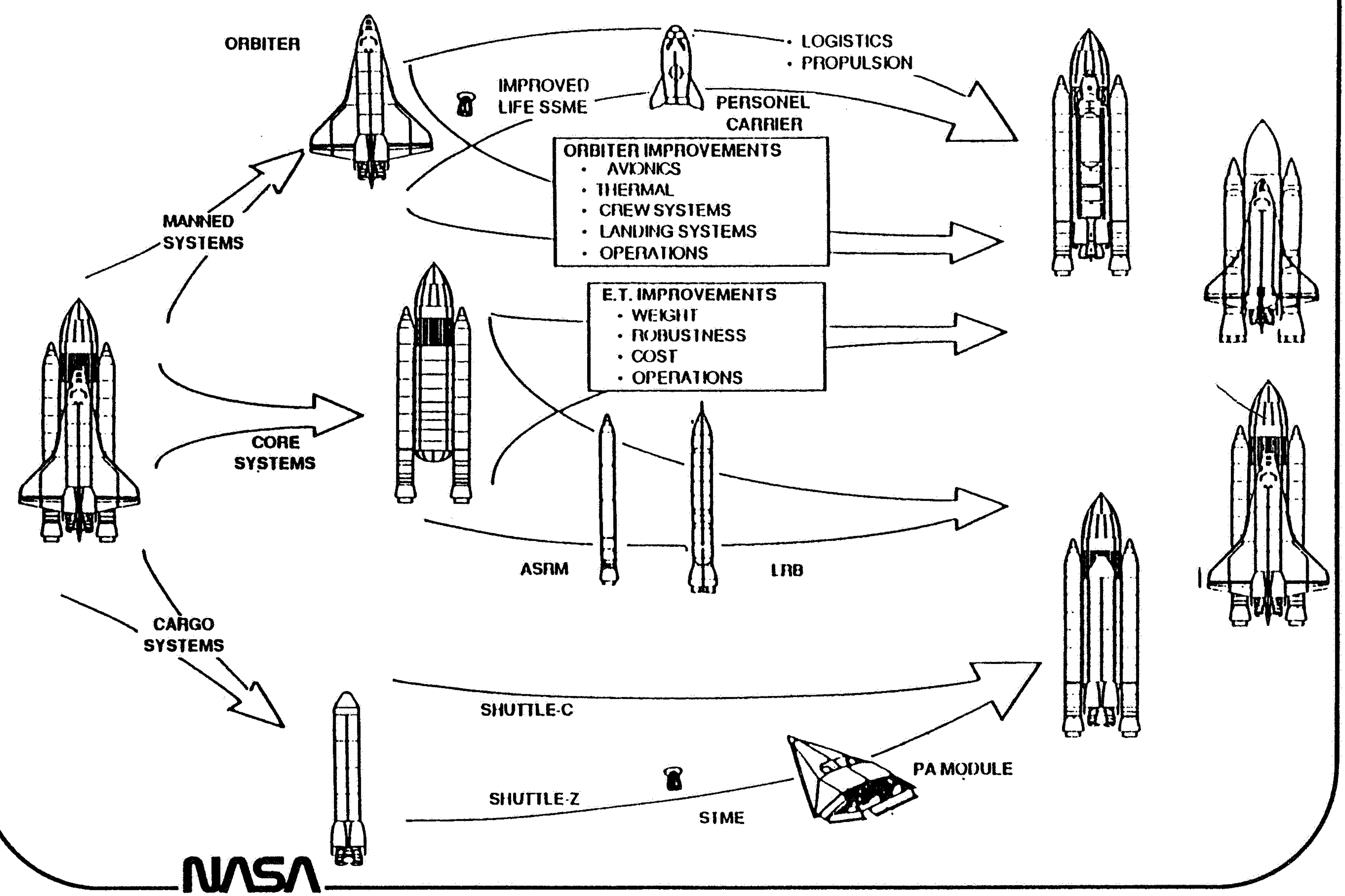
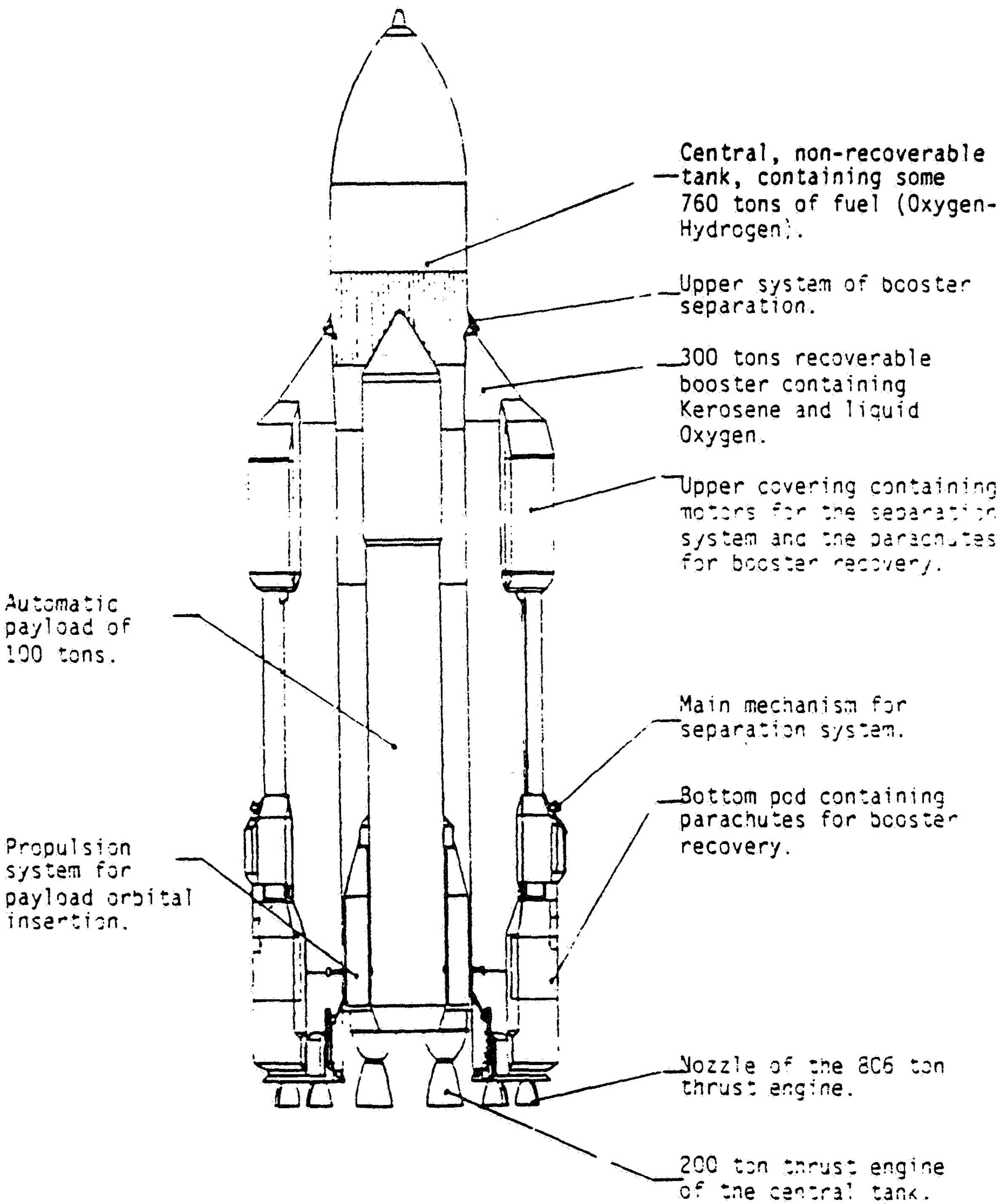
NEXT MANNED TRANSPORTATION SYSTEM

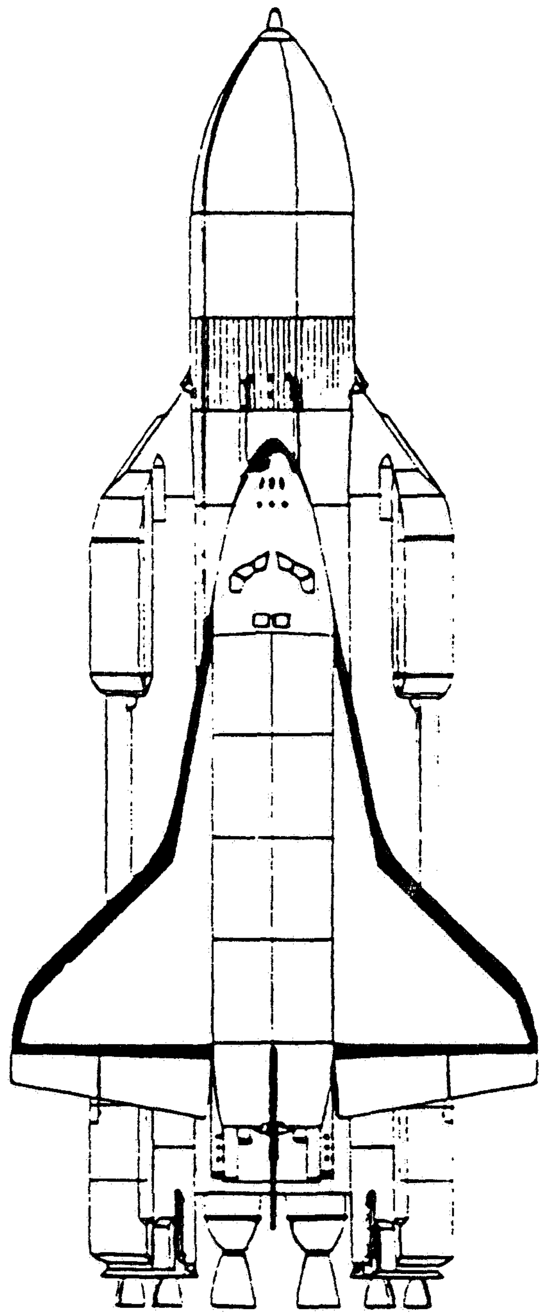
Shuttle Evolutionary Path

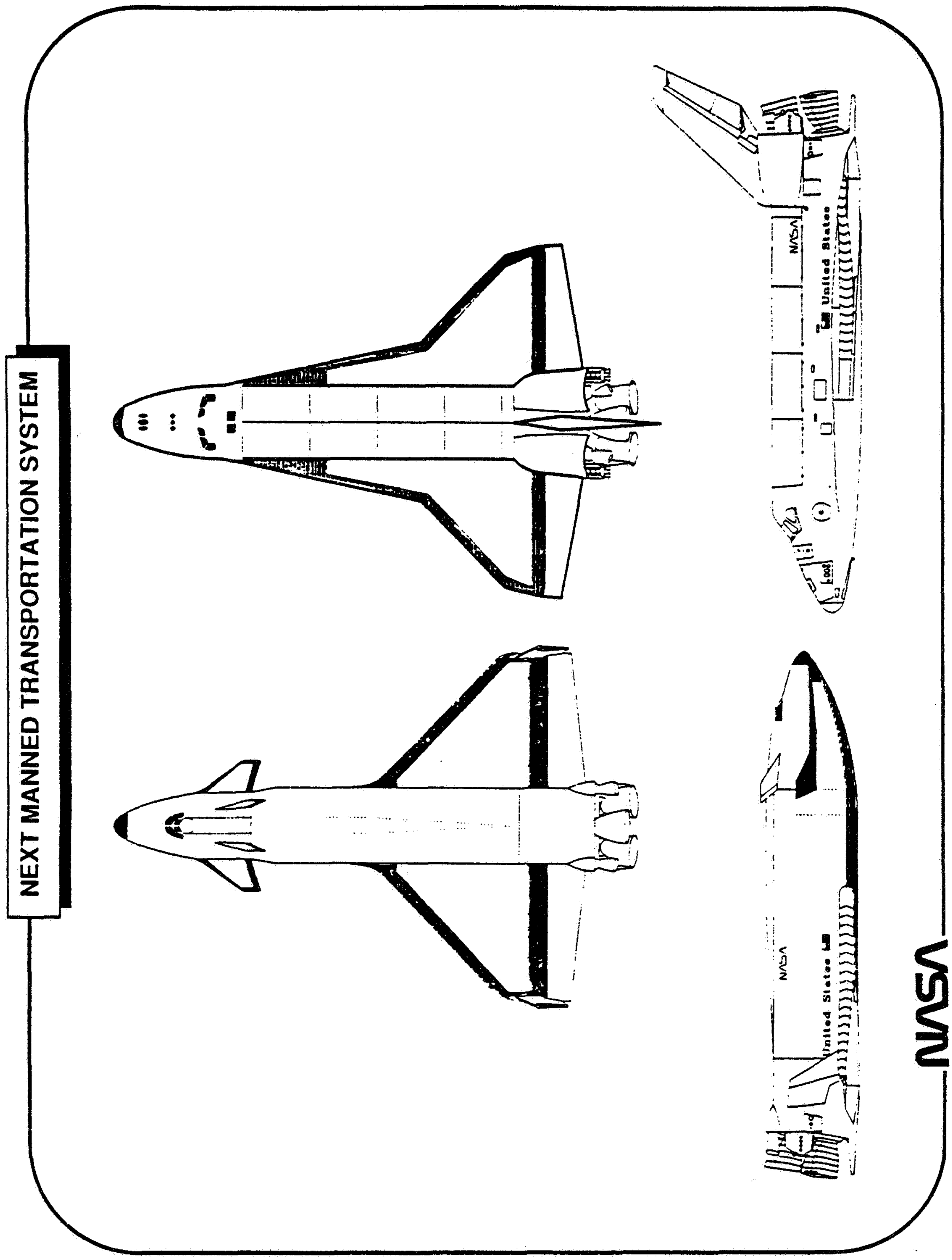


Configuration of the super-heavy Energiya booster, with automatic payload



Super-heavy Booster "Energiya" In Configuration With The Space Shuttle





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NEXT MANNED TRANSPORTATION SYSTEM

Personnel Launch System

- Winged or blunt body
- Increased design margins
- ELV launched
- Configuration/size open
- Limited return cargo capability
- Up payload on cargo vehicle

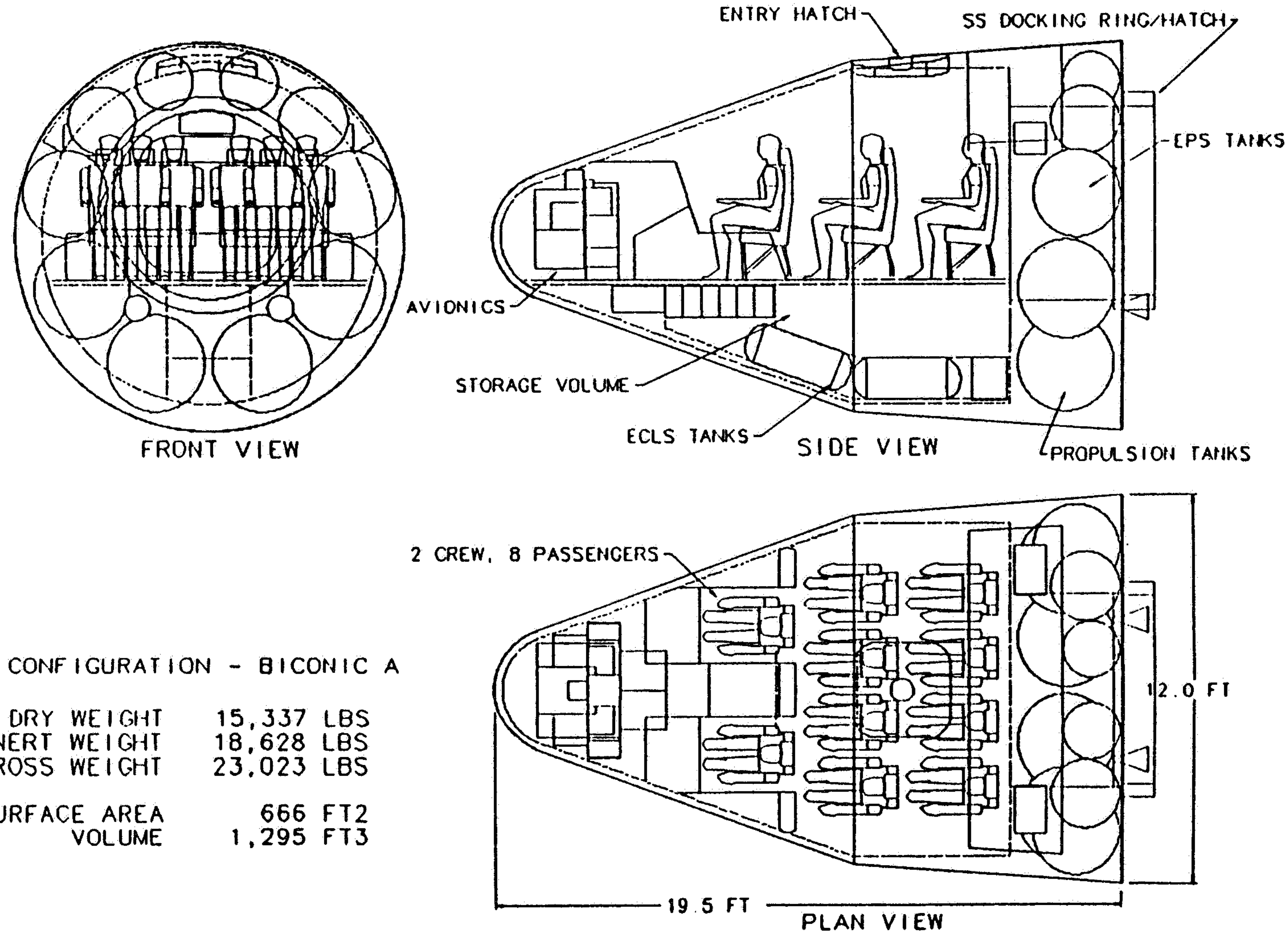
PLS SIZING ISSUES AND CONSTRAINTS

- Number of personnel carried (4 - 16)
    - 8 (dual-trained Station/PLS flight crew)
    - 10 (dedicated PLS flight crew)
- Shuttle payload-bay constraints (CERV application)
    - 15-ft diameter sets PLS maximum body width (assumes folding fins)
- Booster capabilities (easterly for current ELV's)
    - Titan III -- 35,100 lbs
    - Titan IV -- 40,400 lbs
- Entry heating -- ACC, Shuttle HRSI tiles and FRSI blanket insulation
- Landing speed -- 175 knots

NASA

NEXT MANNED TRANSPORTATION SYSTEM

Personnel Launch System



PLS CONFIGURATION - BICONIC A

DRY WEIGHT	15,337 LBS
INERT WEIGHT	18,628 LBS
GROSS WEIGHT	23,023 LBS
SURFACE AREA	666 FT2
VOLUME	1,295 FT3

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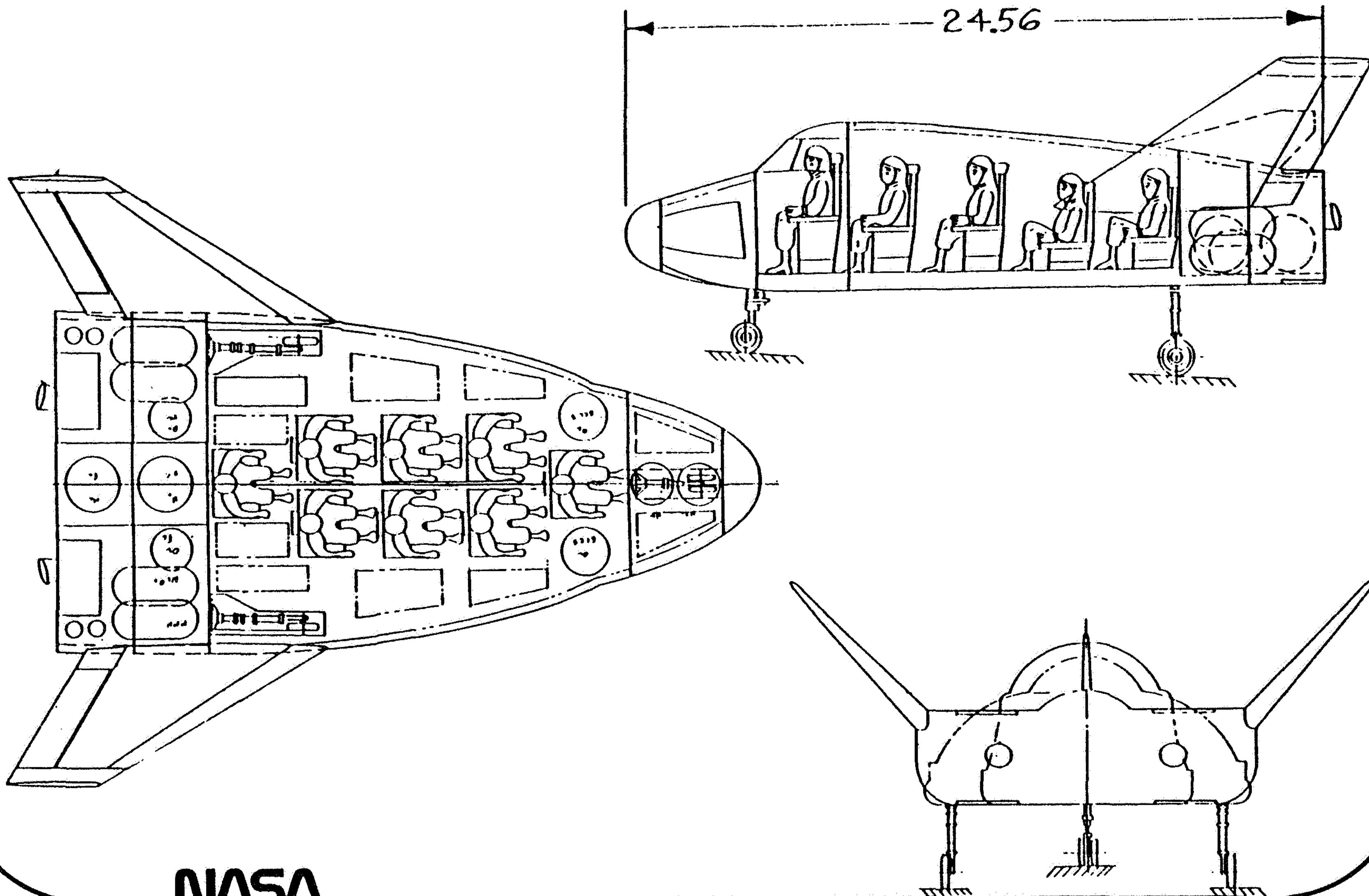
NEXT MANNED TRANSPORTATION SYSTEM

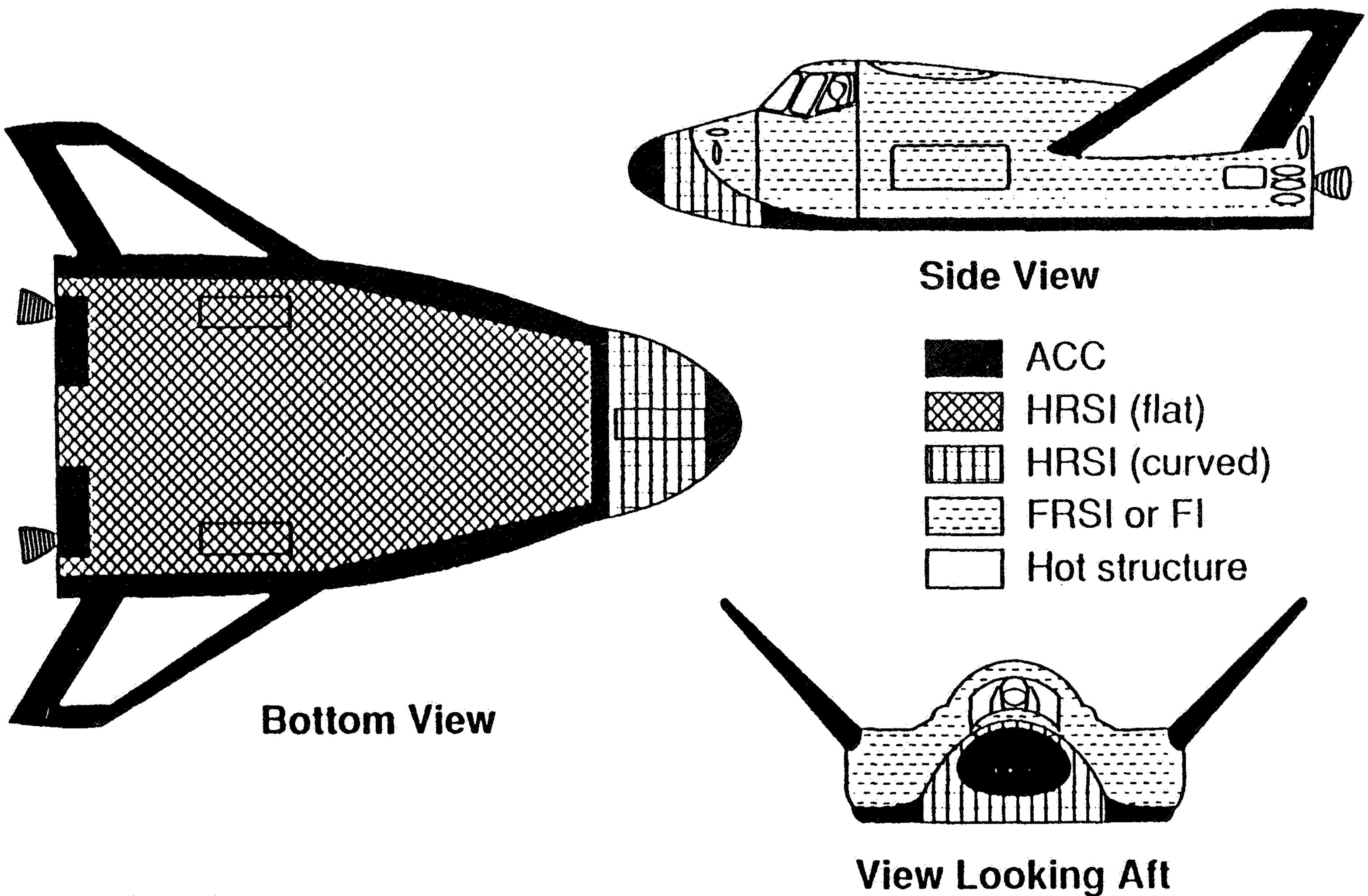
EIGHT MAN PLS

INBOARD PROFILE



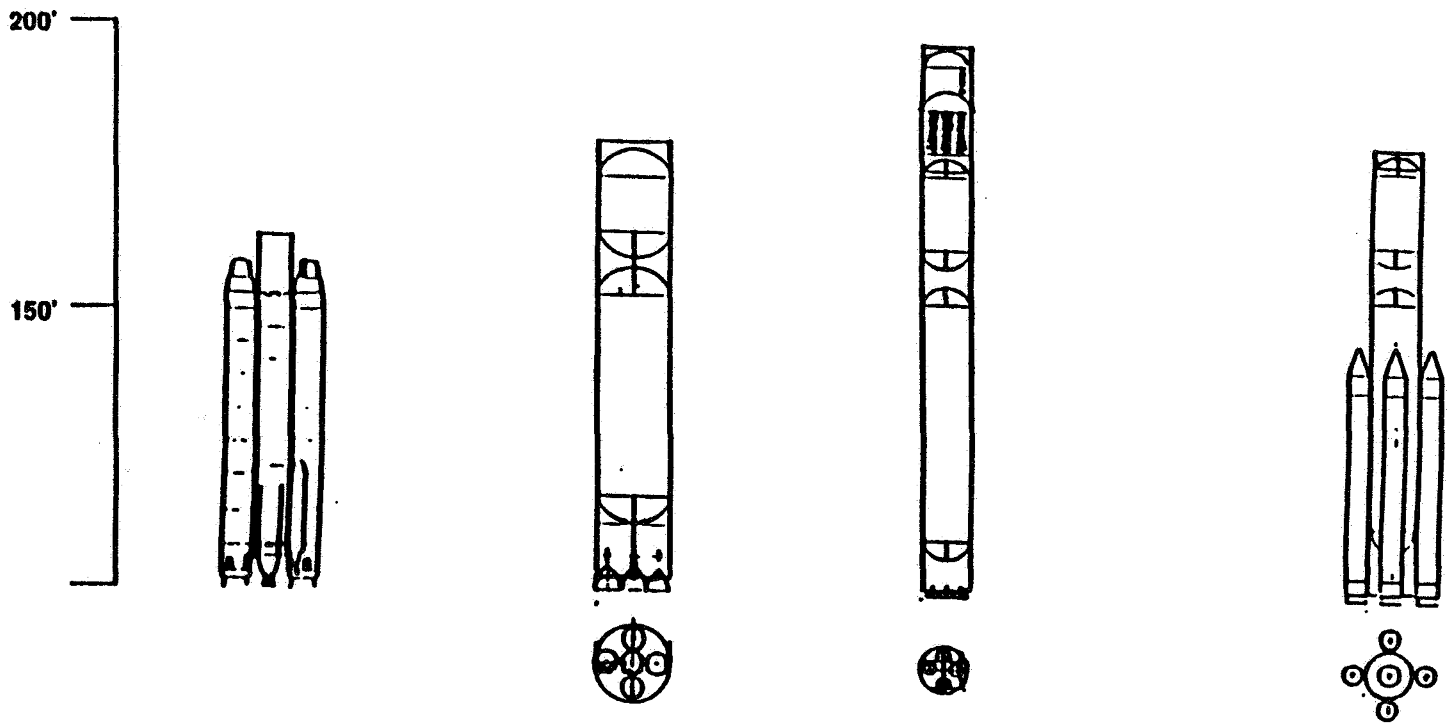
NEXT MANNED TRANSPORTATION SYSTEM

PLS THERMAL PROTECTION SYSTEM



NEXT MANNED TRANSPORTATION SYSTEM

PLS LAUNCH VEHICLE CONCEPTS



	• TITAN IV	• ALS CORE 5 STME	• STS/LRB 4 STME	• STS/LRB 1 STME
	• 7 SEG OR SRMU	• STAGED 2/2	• NEW UPPER STAGE 6 RL-10	• 4 SOLIDS EQUIVALENT TO 1 STS/SRB
ETR/LEO PERFORMANCE (KLBS)	37 OR 48	52	42	38

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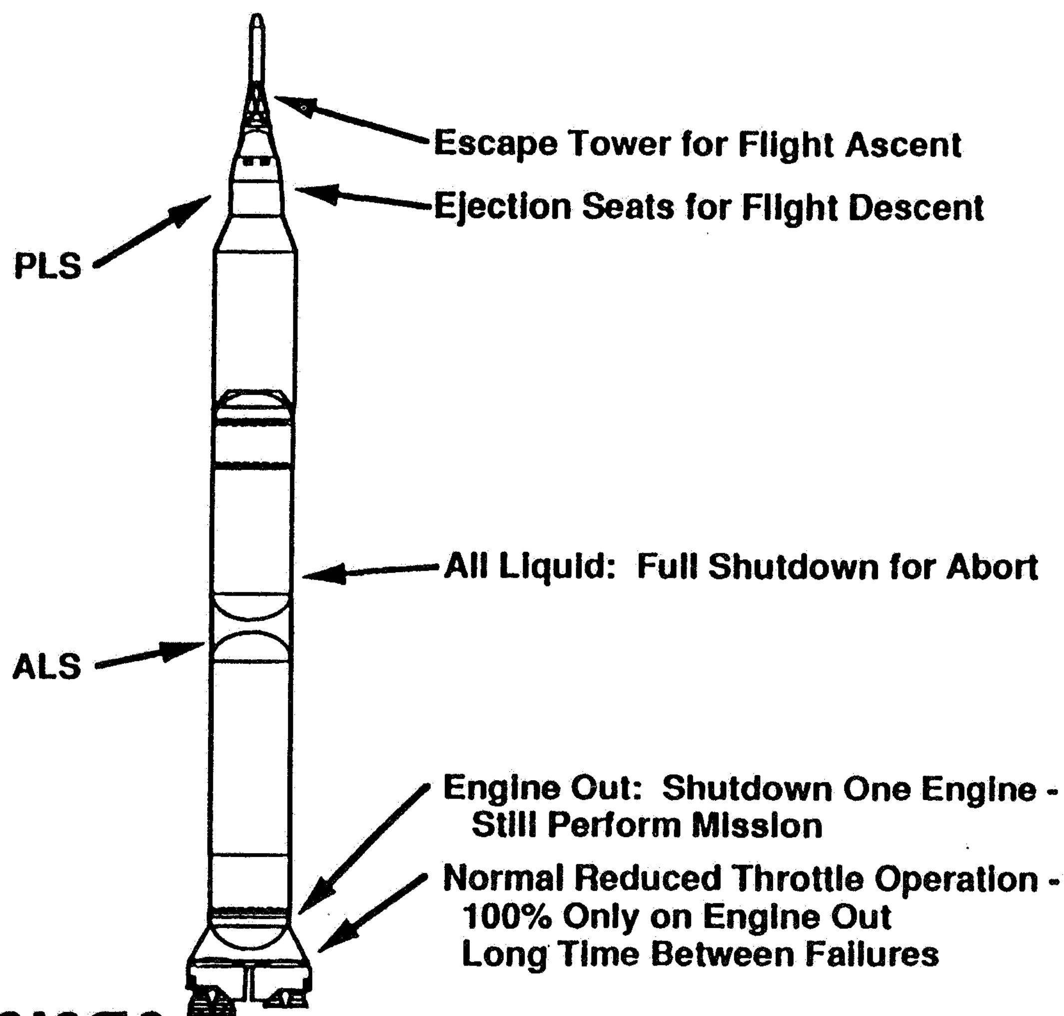
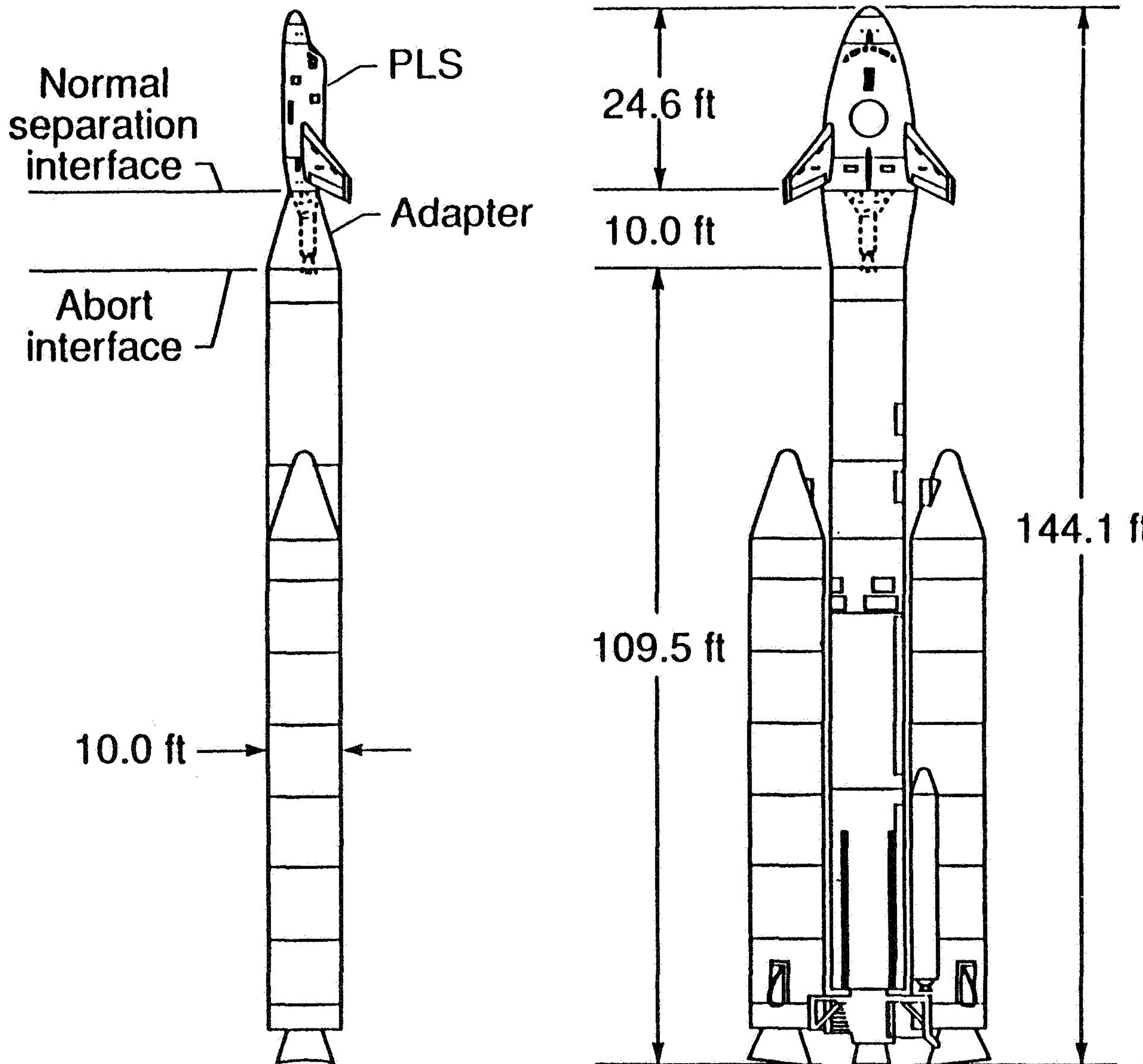
NEXT MANNED TRANSPORTATION SYSTEM

Reliability and Safety



NEXT MANNED TRANSPORTATION SYSTEM



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NEXT MANNED TRANSPORTATION SYSTEM

Advanced Manned Launch System

- Exploit new technologies fully
- Improve design margins
- Configuration/size open
- People-only option available

NASA

NEXT MANNED TRANSPORTATION SYSTEM

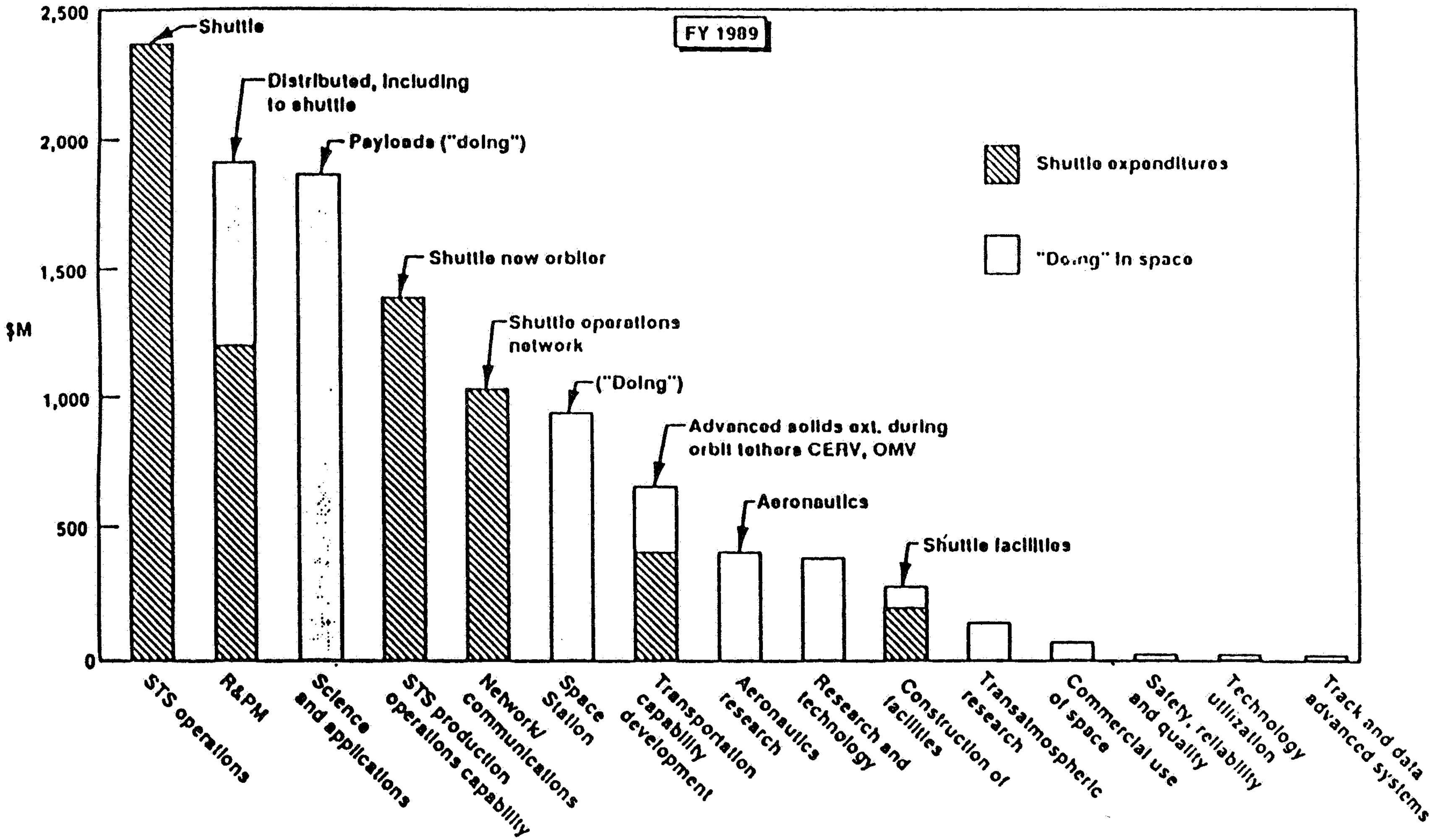
The Problem

- Cost of ownership of the shuttle is too high

The Solution

- New technology hardware can help
  - ALS
  - Code R Base
  - Pathfinder
  - IRAD
  - NASP
  - CSTI
  - SDI
  - Space Station Freedom
- Changes in operations methods can help
- New transportation systems can help

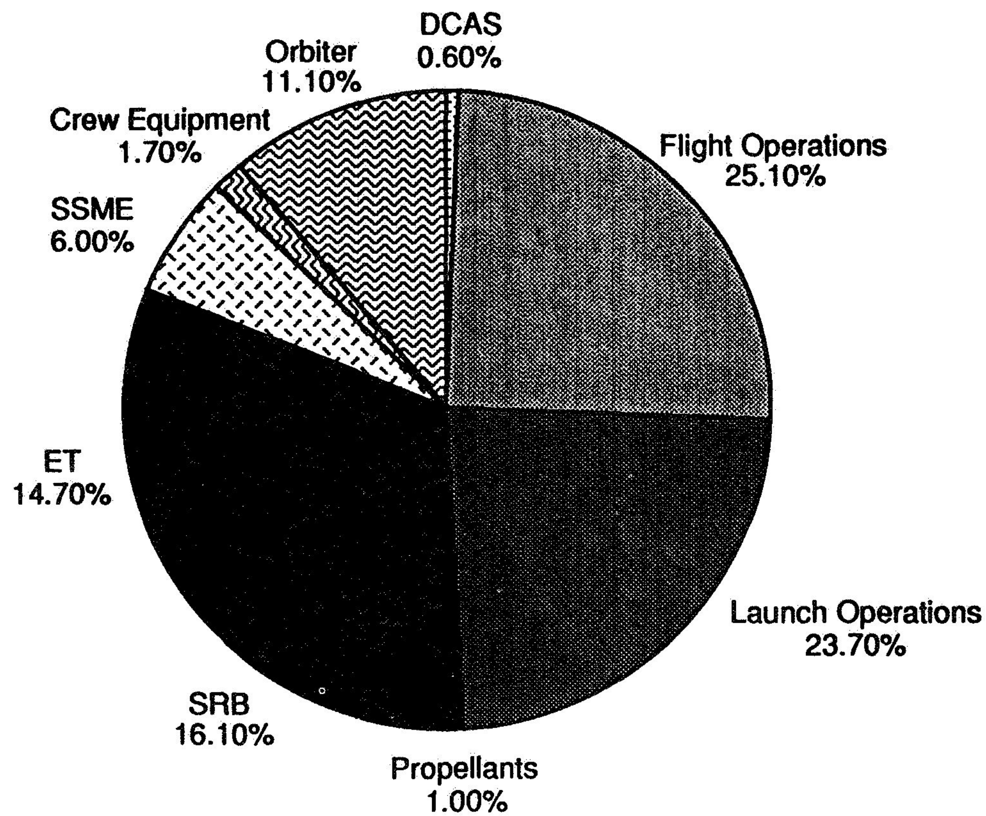
NEXT MANNED TRANSPORTATION SYSTEM



Shuttle funds dominate the NASA budget

NEXT MANNED TRANSPORTATION SYSTEM

STS Average Cost Per Flight (FY89-91) FY89 OMB Budget



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NEXT MANNED TRANSPORTATION SYSTEM

<u>Near-Term Goals</u>

1. **Assured continuity of manned access to space**
   - What happens if/when we lose another shuttle?
   - Consider additional or alternate vehicle

2. **Assured transportation to orbit and assembly of Space Station Freedom**
   - What if STS goes down during the assembly sequence?
   - A permanently manned Space Station implies continuity of support.

3. **Improvements in overall crew safety**
   - Improve current STS
   - New vehicle with better abort capability
   - Emergency crew rescue

4. **Substantial reduction in operating cost**

NASA

NEXT MANNED TRANSPORTATION SYSTEM

Near-Term Issues

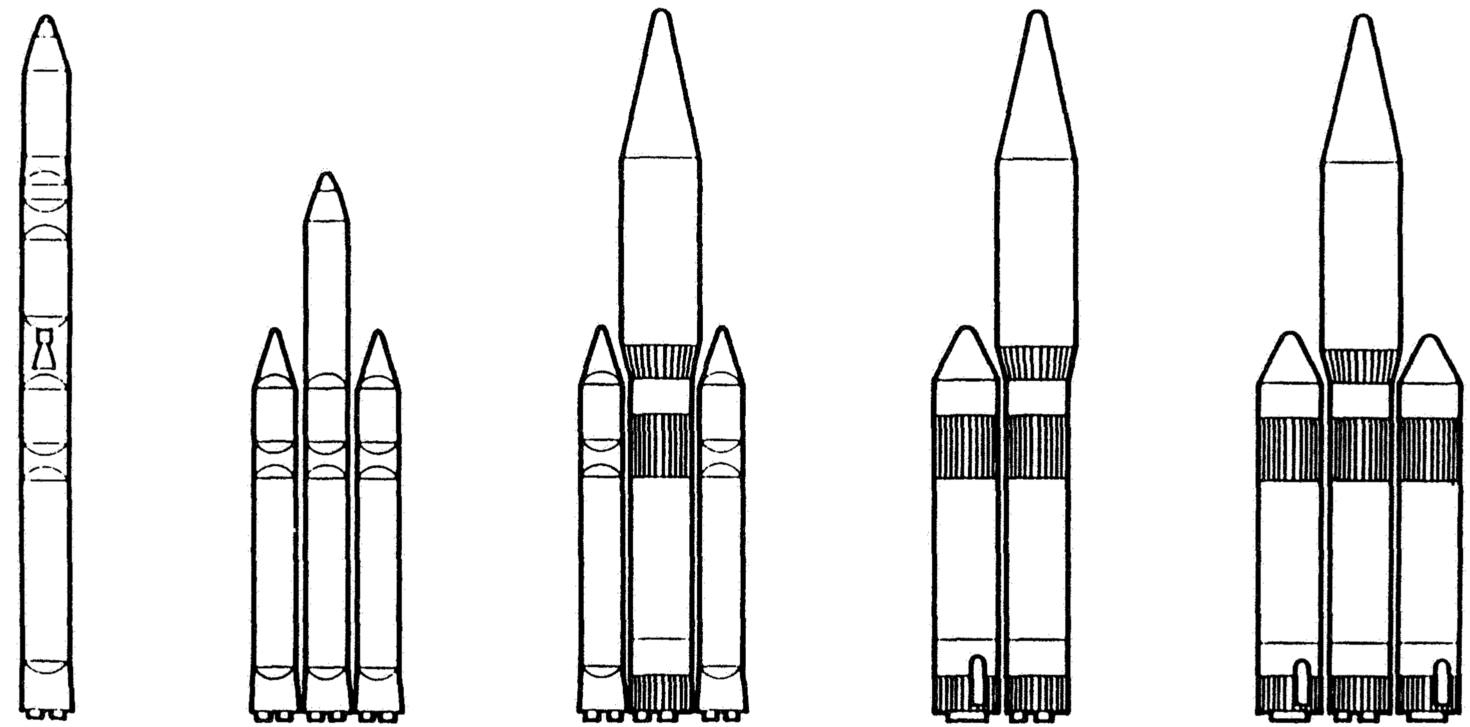
1. Can STS costs be reduced? (How? How much?)
2. Will DOD develop ALS, LRB, STME? (When?)
3. What should NASA do in the meantime?
   a. Design CERV to enable PLS? (Capsule or lifting body?)
   b. Optimum mix of STS/ELV's for cargo?
   c. Further investment in basic STS?
      - More orbiters, OV106, OV107, etc.
      - ASRM
      - Orbiter auto return
      - STS-C, C', Z
      - LRB
      - STME
      - Escape pod
4. What is impact of Lunar/Mars?

EACH ISSUE HAS LONG-TERM IMPLICATIONS.

MOST IMPORTANT FEATURE IS OPERATING COST.

NASA

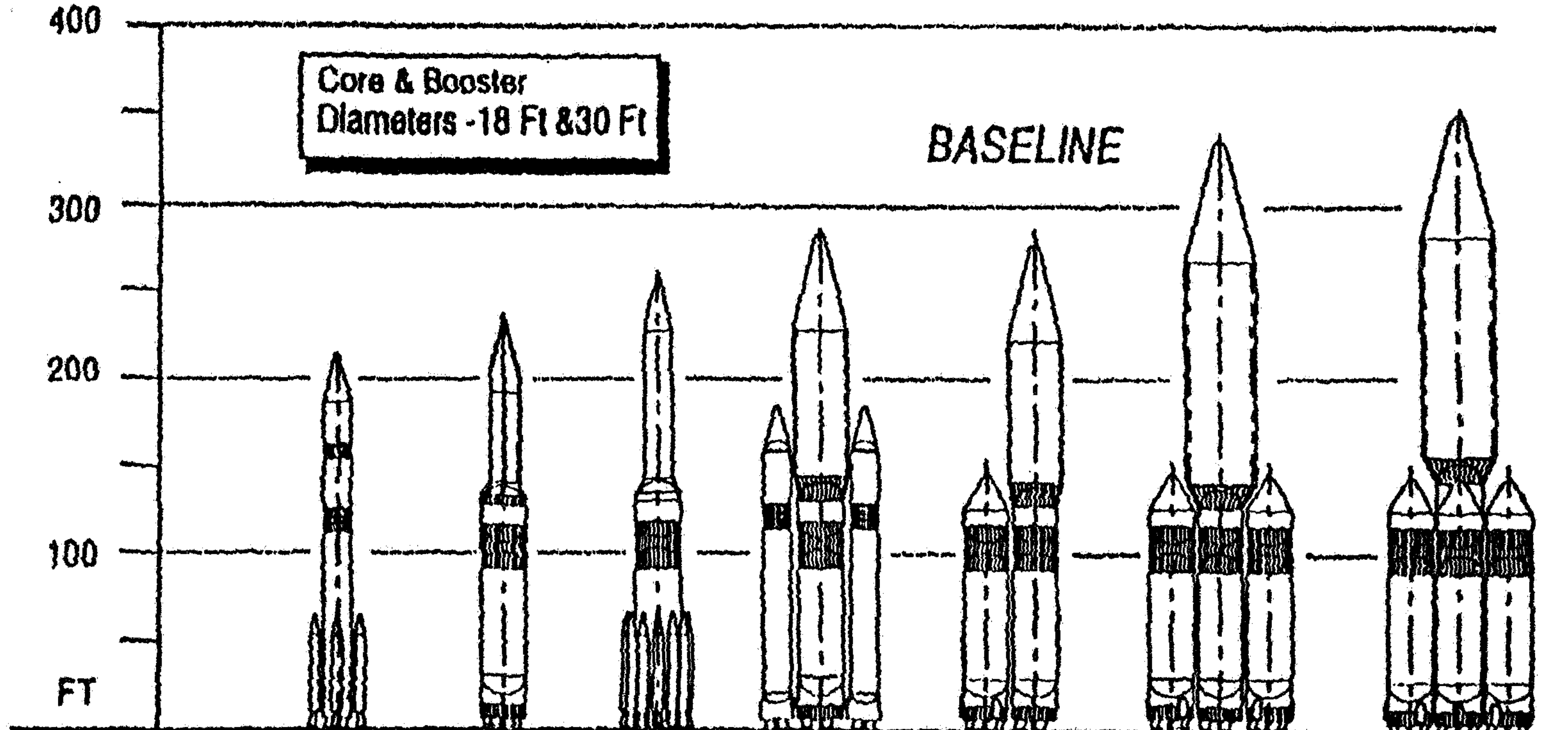
EXAMPLE ALS/LRB FAMILY



	LRB Stand-alone	LRB core + 2 LRBs	ALS core + 2 LRBs	ALS Baseline	ALS expanded model
LEO Payload	40 Klb	80 Klb	100 Klb	150 Klb	226 Klb

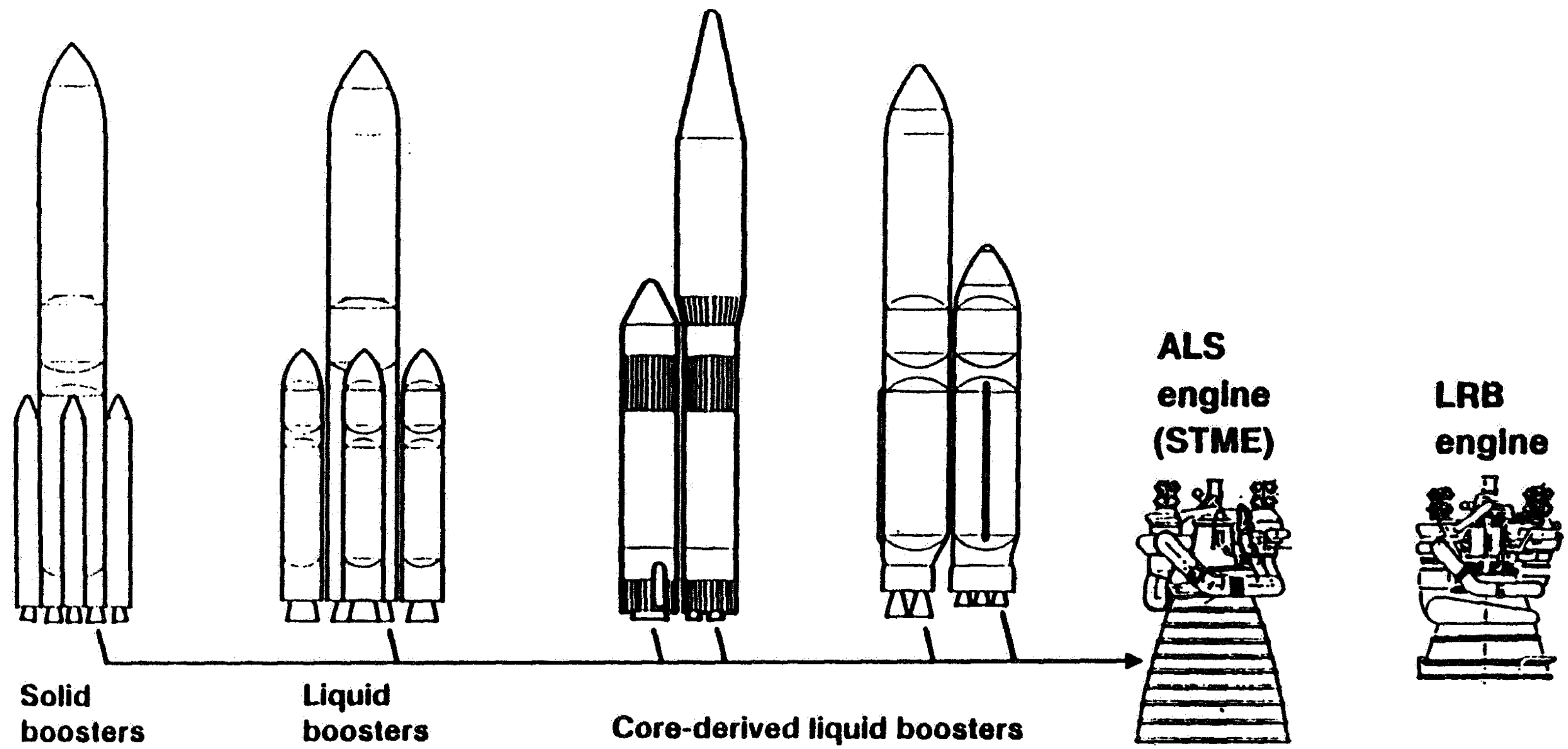
NEXT MANNED TRANSPORTATION SYSTEM

THE ALS FAMILY



	ALS-B(S)	ALS-L1.5	ALS-S12	ALS-BL2	ALS-L	ALS-L2	ALS-L4
RATED PAYLOAD	~10 KLB	~40 KLB	76 KLB	117 KLB	120 KLB	224 KLB	451 KLB
GLOW	TBD	TBD	3.52 MLB	3.47 MLB	3.56 MLB	5.31 MLB	9.13 MLB
BOOSTER PROP.	SOLID	O2H2	SOLID	O2H2	O2/H2	O2/H2	O2/H2

ALS CONCEPTS

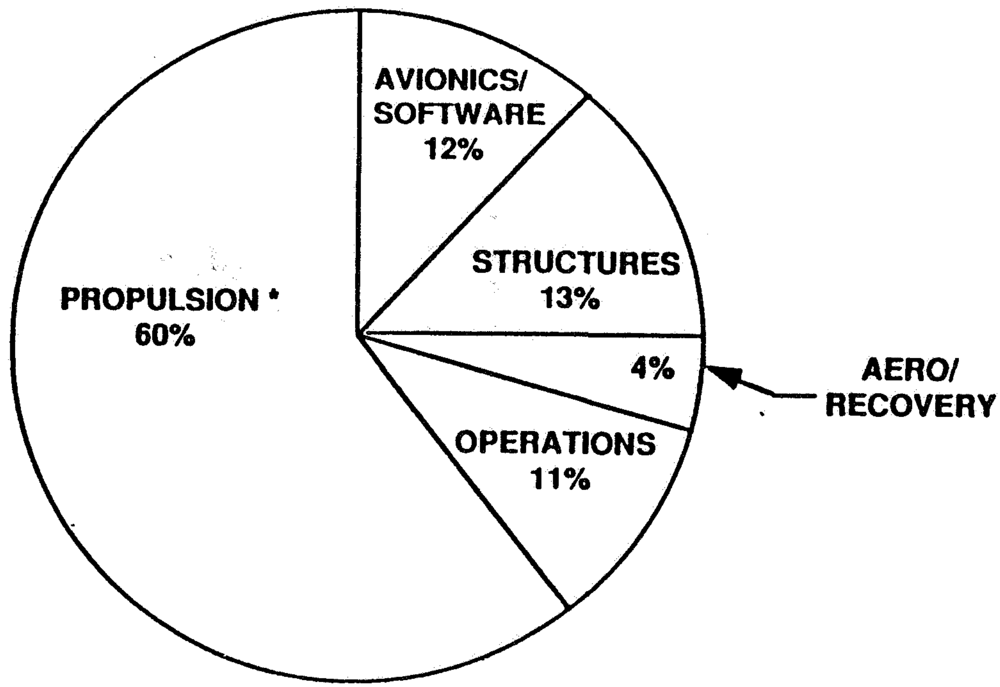


	USAF	NASA
Propellants	O_2/H_2	O_2/H_2
Thrust (Klb–vac)	580	558
Chamber pressure (psia)	2250	2250
Expansion ratio: Core	62	–
(Booster)	39	20
Throttle range	N/A	+0% –25%

A common engine is feasible for ALS and LRB

NASA

ALS Advanced Development Program
87 - 92 Program



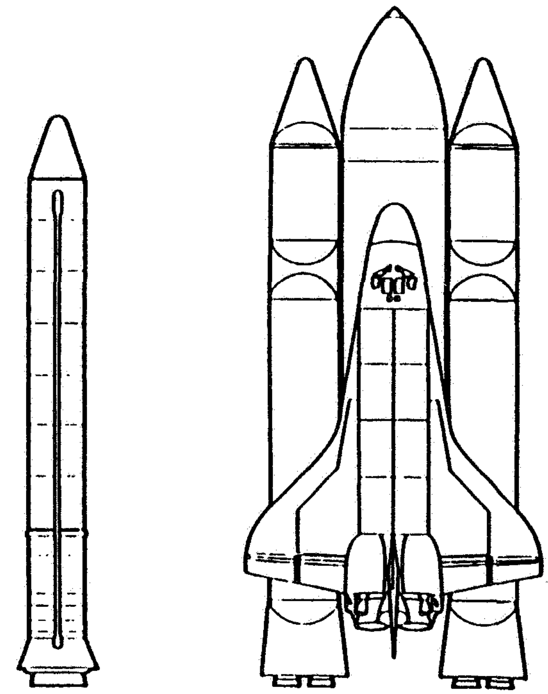
* PROPULSION +
PROPULSION RELATED
EQUALS 67%

LIQUID ROCKET BOOSTERS OFFER SUPERIOR . . .

Safety	— because of their ability to be shut down on command
Performance	— greater than 30% performance improvement for STS
Environmental Cleanliness	— primary exhaust product is steam
Versatility	— well suited to a variety of applications
Launch Operations	— 25% reduction in time-to-launch because LRBs are handled empty, without hazardous propellants

NASA

THE STS LIQUID ROCKET BOOSTER

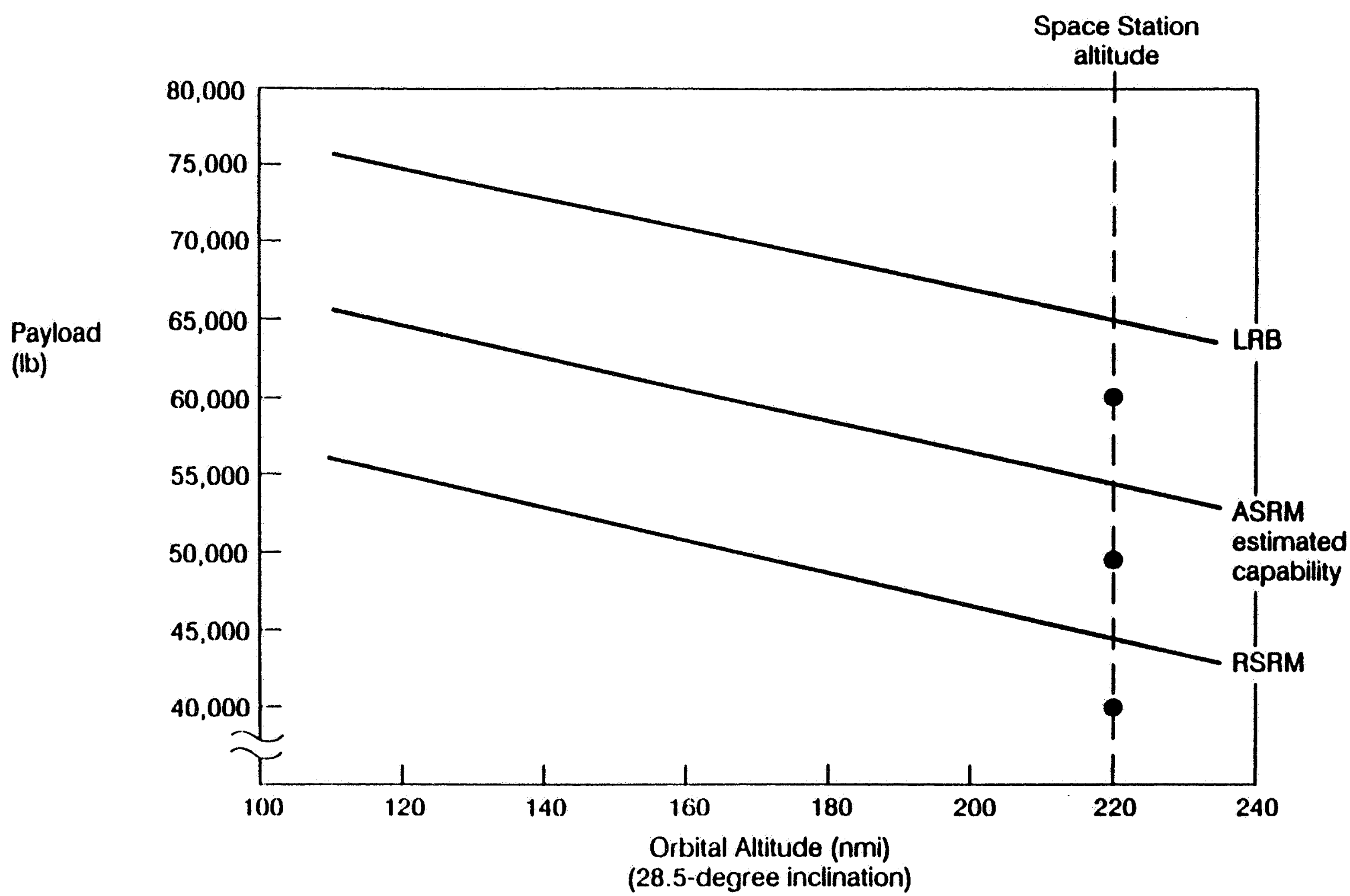


	SRB	LRB
Length (ft)	149	178
Diameter (ft)	12.2	18
Booster dry weight (lb)	146,000	122,000
Booster gross weight (lb)	1,250,000	821,000
Engine thrust at sea level (lb)	2,912,000	4 × 515,000

Features

- LH2/LO2 propellants
- 2219 aluminum tankage
- New low-cost, pump-fed engines
- 4 engines per booster
- Expendable (engines may be recovered)
- Existing technologies

SHUTTLE PERFORMANCE



NEXT MANNED TRANSPORTATION SYSTEM

Basic Requirements

For Future Manned Transportation Earth To/From Earth Orbit

1. The system must be truly operational
   - Reliable
   - Resilient
2. Low Operating Cost

STS does not currently meet these criteria

Can a new system meet the criteria?

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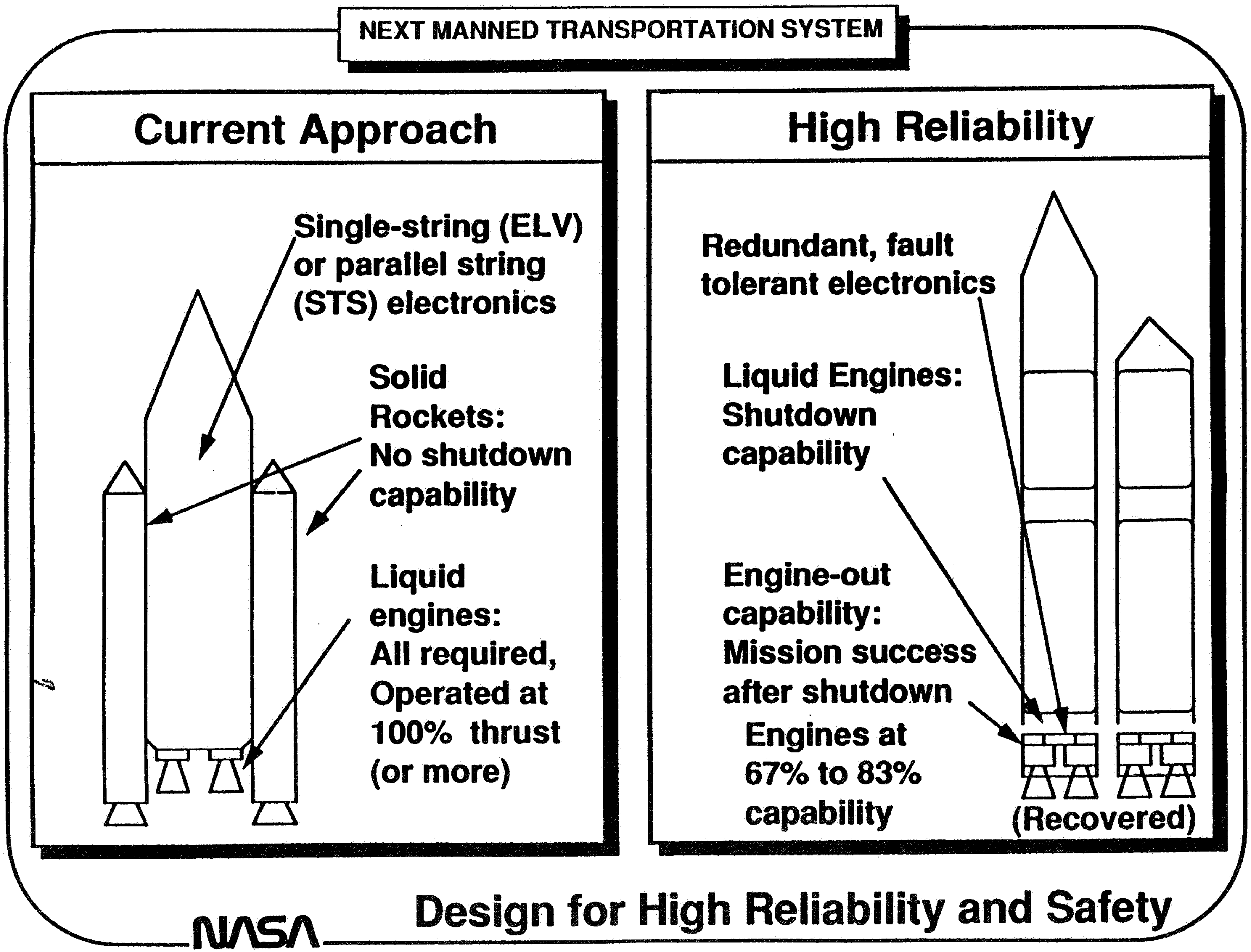
NEXT MANNED TRANSPORTATION SYSTEM

Reliability

Definition: Probability that a flight will proceed successfully from launch through landing.


NEXT MANNED TRANSPORTATION SYSTEM
Current Approach
Single-string (ELV) or parallel string (STS) electronics
Solid Rockets: No shutdown capability
Liquid engines: All required, Operated at 100% thrust (or more)
High Reliability
Redundant, fault tolerant electronics
Liquid Engines: Shutdown capability
Engine-out capability: Mission success after shutdown
Engines at 67% to 83% capability
(Recovered)
NASA
Design for High Reliability and Safety

NEXT MANNED TRANSPORTATION SYSTEM

Resiliency

Definition: Ability of the system to readily recover from effects of flight failures and resulting stand-down times

NASA

NEXT MANNED TRANSPORTATION SYSTEM

Resiliency/Interchangeability

- Ability to guarantee assured access to Space Station Freedom is required during its assembly and operations/maintenance
- Probability of shuttle loss resulting in long down-time is presently high
- Methods to guarantee resiliency are required; i.e.,
  - An alternate manned launch vehicle
  - Design interchangeable propulsion sytems for shuttle and shuttle derivatives

NASA

NEXT MANNED TRANSPORTATION SYSTEM

Definition of Man-Rating

- A man-rated space system incorporates those design features and requirements necessary to accommodate human participants.
- It provides the capability to safely conduct manned operations, including safe recovery from any credible emergency situations.
- Man rating is the process of evaluating and assuring that the hardware and software can meet prescribed, safety-oriented design and operational criteria.
- It is an integral part of the design, development, verification, management, and control process.
- It continues throughout the operational life of the system.

NASA

NEXT MANNED TRANSPORTATION SYSTEM

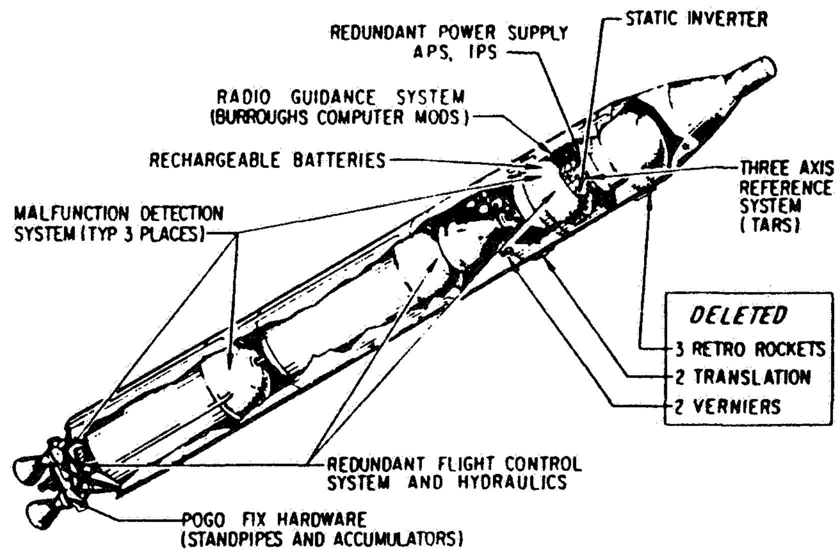
Man-Rating the Titan II

Major hardware changes between the Titan II and the Gemini Launch Vehicle consisted of those items which enhanced mission success or crew safety, permitted vehicle compatibility with the spacecraft, and accomplished weight savings.

- The transition section between the spacecraft and launch vehicle
- The radio guidance system
- The electrical power supply
- Deletion of rocket motors
- Addition of Pogo hardware
- Redundant flight control
- Malfunction detection systems

NASA

NEXT MANNED TRANSPORTATION SYSTEM



Gemini Launch Vehicle configuration and modifications.

NEXT MANNED TRANSPORTATION SYSTEM

Conclusions

1. Current STS performs multiple functions extremely well
   - But does not meet top-level criteria
2. Operational support of Space Station places extra level of requirements for resilience in manned space transportation
3. NASA should anticipate loss of another shuttle
   - Inherent reliability limitations and frequent flights make it "not if, but when"

NASA

NEXT MANNED TRANSPORTATION SYSTEM

Conclusions

4. Operations costs dominate total yearly costs
   - For all cases, current systems & new systems
   - DDT&E relatively small
   - Potential large return for small investment
5. Achieving low-cost operation
   - Special purpose vehicles to match function
   - Emphasis on operability during design
   - Integrate STS/SSF/lunar programs
   - Incentives for NASA & contractor management

NEXT MANNED TRANSPORTATION SYSTEM

Conclusions

6. Breakthroughs needed in both reliability and total cost of operations
   - Current options may or may not meet criteria
     - Advanced technology may be required
   - Ongoing manned spacecraft design activity needed to identify & exploit breakthroughs
7. Timing of shuttle replacement is not clear
   - Operations cost analysis of alternate systems needed
     - Include total yearly costs of current and alternate systems

NASA

NEXT MANNED TRANSPORTATION SYSTEM

Why STS Operations Goals Were Not Achieved

- Early STS budget cuts necessitated de-emphasis on operations
  Examples: 1) Orbiter payload bay doors
  2) Onboard fault isolation

- Very complex design
  Examples: 1) SSME turbo blade inspection
  2) Orbiter thermal protection system
  3) SRB segment assembly

- Design and operations were not closely integrated

NASA

NEXT MANNED TRANSPORTATION SYSTEM

Life-Cycle Costs

Definition: Nonrecurring costs of development and procurement

+

recurring costs of maintenance and operations.

NEXT MANNED TRANSPORTATION SYSTEM

Technologies/Guidelines to Reduce Operational Costs

- Simplified interfaces and systems
  - Especially propulsion and payload accommodations
- Onboard checkout/fault isolation
- Automated work control/problem status system
- Minimal weather constraints
- Simple, durable thermal protection system
- Performance margins

NASA

NEXT MANNED TRANSPORTATION SYSTEM

IS A NEW MANNED SYSTEM NEEDED? **YES**

- STS too costly
- Manned system should have first stage abort capability
- Obsolescence
- Assured manned access needed
- Functional requirements are changing

- People to/from orbit
- Cargo to orbit
- Orbital experiments
- Return cargo
- Maneuvering & servicing

- New system more efficient
- Cargo vehicles more efficient
- SSF more efficient
- Requirement is soft
- Servicing economics are soft

NEXT MANNED TRANSPORTATION SYSTEM

IS A NEW MANNED SYSTEM NEEDED?

NO

- STS satisfies most requirements
  - People to/from orbit
  - Cargo to orbit
  - Orbital experiments
  - Return cargo
  - Orbital maneuvering and servicing
- Capitalize on large investment
- Scarce DDT&E funds needed for SSF and Lunar/Mars
- Paper systems always cheaper than real systems
- High operating costs are independent of system configuration

NASA

NEXT MANNED TRANSPORTATION SYSTEM

Improvement is Possible

- To make a better/safer shuttle
  - Shuttle evolution
  - LRB's which allow first-stage abort
- To improve environmental impact
  - LRB
- To plan for assured manned access to space
  - PLS
  - ALS
  - More Orbiters
- To reduce high Ops costs
  - LRB
  - Shuttle evolution

NASA

NEXT MANNED TRANSPORTATION SYSTEM

Choosing Among Alternatives

Shuttle	Shuttle Evolution
ASRM	LRB
Shuttle-C	
Shuttle Derived Heavy Lift	ALS
	PLS
↓	↓
Solid Rocket Booster Choices	Liquid Rocket Booster Choices

NASA

NEXT MANNED TRANSPORTATION SYSTEM

One Possible Choice

- Evolve Shuttle
  - Add LRB
  - Limit crew size so first stage abort is possible
  - Use for launching high-valve payloads, down payloads, and for backup for large crews
- Develop ALS for modular HLLV capability for routine cargo launches
- Develop PLS with first-stage abort for routine crew launches

NASA

NEXT MANNED TRANSPORTATION SYSTEM

Avionics Requirements

Safety Improvements

- Manned rating
  - Malfunction detection and abort implementation
- High-reliability systems/hardware
- High mission success for both manned and cargo

Operations Cost Improvements

- Onboard checkout and fault isolation
- Improve ground turnaround operations
- Low-cost systems/hardware

NASA

MANNED SPACE TRANSPORTATION SYSTEMS

Manned transportation is required in four areas:

1. Earth-to-orbit arena
2. Onorbit arena
3. Transfer systems arena
4. Planetary surface systems arena

NASA

MANNED SPACE TRANSPORTATION SYSTEMS

1. Earth-to-Orbit Arena
   - Unmanned systems
   - Manned systems
     - "Routine" access to Earth orbit
       - Current System
         - Shuttle
       - Future Systems
         - Shuttle Evolution
         - PLS
         - AMLS
         - NDV's
     - Rescue/Emergency Access ETO
       - Shuttle Rescue
       - CERV
       - Alternate Access Options
       - International Alternatives

MANNED SPACE TRANSPORTATION SYSTEMS

2. Onorbit arena
   - Unmanned systems
   - Manned systems
     - Permanently Occupied Facilities
       - SSF Hab Modules
       - SSF Lab Modules
     - Man-tended Facilities
       - EDO
       - MTFF
       - ISF
     - EVA Activities/Environments
       - Obiter Payload Deploy/Retrieval
       - SSF Assembly
       - Lunar/Mars Vehicle Assembly
       - Servicing Activities
         - from Orbiter or Other Nodes
       - Emergency EVA Activities

MANNED SPACE TRANSPORTATION SYSTEMS

3. Transfer systems arena
   - Unmanned systems
   - Manned systems
     - Activities in Earth Orbit
       - Manned OMV's
     - Transfer Between Earth & Moon
       - Manned STV's
       - Lunar Landers
       - Rescue Options
     - Transfer Between Earth & Mars
       - Variable Gravity Facility (VGF)
       - Zero Gravity Vehicle Options
       - Transfer Options Between Moon & Mars
       - Rescue Options

MANNED SPACE TRANSPORTATION SYSTEMS

4. Planetary surface systems arena
   - Unmanned systems
   - Manned systems
     - Mobile Systems
       - Surface EVA Systems
       - Land Rovers
       - Aerial Systems
       - Mobile Temporary Shelters
     - Stationary Systems
       - Habitats
       - Laboratories
       - Shops, Processing Facilities
       - Permanent Emergency Shelters

NASA

CRITICAL HUMAN FACTORS DESIGN CONSIDERATIONS

CONSUMABLES REQUIREMENTS

Food, Water, Oxygen, Clothing, Tools/Supplies, Emergency Supplies, EVA Systems

ENVIRONMENTAL REQUIREMENTS

- Volume per Person
- Gravity Environment
- Workload Conditions
  - Mission Requirements
  - Housekeeping Requirements
- Orientation Cues
- Odor Control/Requirements
- Temperature Control/Requirements
- Radiation & Contamination Detection & Protection
- Off-Duty Activities Requirements
- Exercise Requirements
- Crew Comfort/Ergonomics Requirements
- "Ease of Operation" Requirements
- Communications
- Windows & Other Visuals
- Waste Management (Personal & Trash)
- Personal Hygiene Requirements
- Emergency Procedures/Options
- Safe Havens
- Medical Requirements
- Storage Requirements
- Psychological Environment
  - Crew Mix
  - Training/Counselling
  - Color Requirements
- Repair/Maintenance Requirements
- Recycling Requirements

CRITICAL HUMAN FACTORS DESIGN CONSIDERATIONS

ENGINEERING FACTORS

Structures; Materials; Systems Engineering (Avionics, Power, Thermal, ECLSS, etc.); Crew Size Requirements; Radiation & Impact Protection; Payload & Storage Requirements; Environmental Requirements

GROUND SUPPORT REQUIREMENTS FOR MANNED SPACE SYSTEMS

Launch Support

Recovery/Return Support

Mission Planning Support

Mission Control Support

Communications & Tracking Support

Medical Support

Training Support

Support from Unmanned Systems

Research & Technology Development Support

710

S30442
44P

PRESENTATION 1.3

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CARGO LAUNCH VEHICLES TO LOW EARTH ORBIT

CARGO LAUNCH VEHICLES TO LOW EARTH ORBIT

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Director, Space Transportation and Exploration Office
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Introduction

The National Space Policy signed by President Reagan on Jan 5, 1988, and the National Space Launch Program Report to Congress signed by President Bush on April 10, 1989, established the basis for assessing the nation's launch vehicle infrastructure. Consistent with the policies and time-phased strategies defined in these documents, reliable access to space will be provided through the use of a mixed fleet of launch vehicles, including the space transportation system (STS), existing expendable launch vehicles (ELVs) and new heavy lift launch vehicles (HLLVs). This will give the Nation the capability to meet the base program needs and accommodate the expanded requirements of human exploration of the Moon and trans-Mars through either a vigorous or a paced deployment of assets. The existing United States space infrastructure provides the launch capability to perform Lunar/Mars robotic missions, assemble Space Station Freedom (S.S. Freedom) and establish it as a transportation node for Lunar and planetary missions.

Current capabilities, augmented with HLLV systems will provide the balanced, flexible, and assured access to space necessary to meet current commitments and perform the bold new initiative recently outlined by the President.

Requirements

There are two primary space transportation capabilities required to support both base program and expanded mission requirements: earth-to-orbit transportation systems and space transfer vehicle systems. Table 1 depicts which existing and new earth-to-orbit (ETO) vehicles are required to support each of these mission requirements. It is evident from this table that current launch vehicles can accommodate the base program mission requirements. However, the expanded mission area will require new launch vehicles. Current ETO capabilities will need to be augmented with a HLLV for lunar missions and a growth HLLV for Mars missions.

Earth-To-Orbit Launch Vehicle	Civil Mission Requirements						
	Base				Expanded		
	SSF Assy/Logistics	Spacelab	Science/Planetary/ Observatories	SSF Accommodations	Precursors	Lunar	Mars
Existing:							
• Atlas					x		
• Delta					x		
• Titan			x		x		
• STS	x	x	x	x		x	x
New:							
• HLLV					x	x	
• Growth HLLV							x

Table 1. ETO Requirements

Base Program

Many types of missions are included in the base program: assembly, logistics, and crew rotation for the S.S. Freedom; servicing of satellites; Spacelab; delivery of communication, science, planetary, and observatory satellites in support of the science, application and technology programs; and mission to planet earth activities. The base program missions are manifested on a mixed fleet consisting of the STS and a stable of ELVs. Existing transportation systems have sufficient performance capabilities to support base program requirements.

Expanded Mission Area — Lunar/Mars Initiative

Robotic Missions

The ETO transportation system is required to support the launch of robotic missions prior to any piloted Lunar/ Mars mission. These robotic missions support the selection of outpost sites, location of potential resources, emplacement of navigation aids, and provide engineering data for the design, development, and operation of the outposts. These missions are also required to augment life science databases to ensure the health and safety of the crew, and to provide communications capabilities needed for the lunar missions. Table 2 shows the planned robotic missions, along with the ETO vehicles currently planned.

Destination	Mission (Flights)	Vehicle
Polar Orbit	Life Sat (10*)	Delta II
Lunar	Lunar Observer (2)	Atlas II
L_2 (Far Side)	Comm Sat (1)	Atlas II
Mars	Global Network (2)	Titan IV
Mars	Sample Return/ Local Rover (2)	Titan IV
Mars	High Res. Imaging/ Comm Orbiter (2)	Titan IV
Mars	Rovers (1)	Titan IV
Mars	Rovers (1)	Titan IV
Mars	Rovers (1)	Titan IV
Mars	Communication Sat. (1)	Titan IV

Note: *Two flights per year for five years.

Table 2. Robotic Precursor Missions

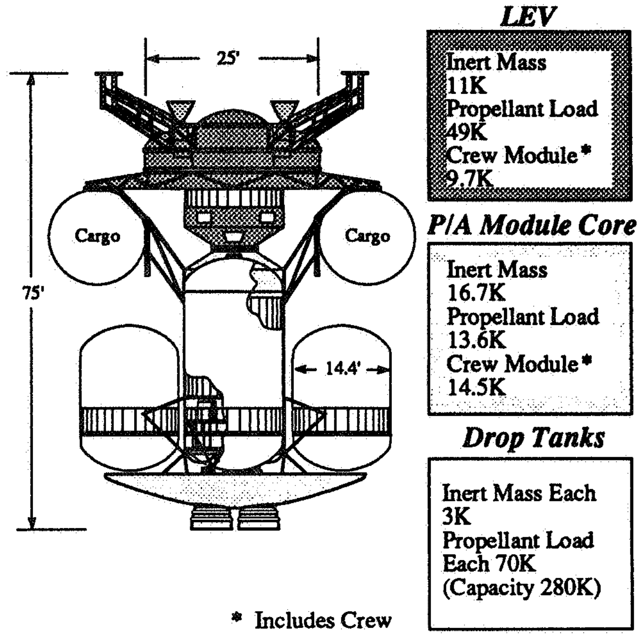


Figure 1. Lunar Transfer and Excursion Vehicles

Lunar Outpost

The mission requirements for the Lunar outpost are partitioned into three phases—the emplacement phase, the consolidation phase, and the utilization phase. The ETO transportation system must ferry vehicles, cargo, crew, and propellant to S.S. Freedom (220 nm altitude) in support of these Lunar outpost phase requirements. Reference capability for a new HLLV to deliver these various payloads to S.S. Freedom is a manifested mass limit of 135K to 157K per flight (with 25 ft and 15 ft diameter shrouds respectively). The LTV/Lunar excursion vehicle (LEV) shown in Figure 1, indicates that the aerobrake and the LEV (25 ft diameter) are the driving components for the large shroud size. The smaller 15 ft shroud provides an adequate volume for the 157K propellant delivery.

A capability to test and process the Lunar transfer vehicles at the S.S. Freedom is needed to meet the required cargo and piloted Lunar launches. Accommodation equipment must be ferried to S.S. Freedom beginning in the mid to late 90s to meet these launch dates for the Lunar outpost.

The mass requirement for payload delivery to S.S. Freedom for each mission in support of the Lunar outpost cover a range of 242K-440K. This mass range is driven by whether the vehicles operate in expendable or reusable mode, the mission is cargo or piloted, and whether Lunar LOX is being utilized. Mass requirements for piloted flights include cargo in addition to the mass of the crew. Approximately 70 to 75 percent of the mass delivered to LEO is LTV propellant. The 15 ft shroud HLLV with a 157K payload capability can deliver two LTV propellant modules to LEO. Initial delivery of an entire single LTV/LEV mission requires two 157K and one 135K HLLV flights.

Mars Outpost

Establishing a permanent, self-sufficient base on the surface of Mars will follow an evolutionary path with emplacement, consolidation, and utilization phases similar to the Lunar outpost. Once again, the ETO transportation system must ferry the vehicles, cargo, crew, and propellant to S.S. Freedom in support of Mars outpost requirements. Additional growth of S.S. Freedom, beyond that required for the Lunar outpost, is required to accommodate MTVs in support of Mars missions beginning in 2015.

The growth HLLV for the Mars outpost requires significantly greater capability than the HLLV used to support the Lunar outpost. An ETO delivery mass of140t is utilized to manifest MTV payloads to be integrated at S.S. Freedom. The reference MTV (Figure 2) illustrates vehicle elements which must be delivered separately and assembled in orbit. The aerobrakes and the trans-Mars injection stage (TMIS) are elements driving the HLLV to a payload shroud of Figure 2. Mars Transfer and Excursion Vehicles 40 ft in diameter and 100 ft in length. Each fueled TMIS stage tank has a mass of 300K. Multiple flights of the growth HLLV will deliver all the elements and propellant of a complete MTV to LEO.

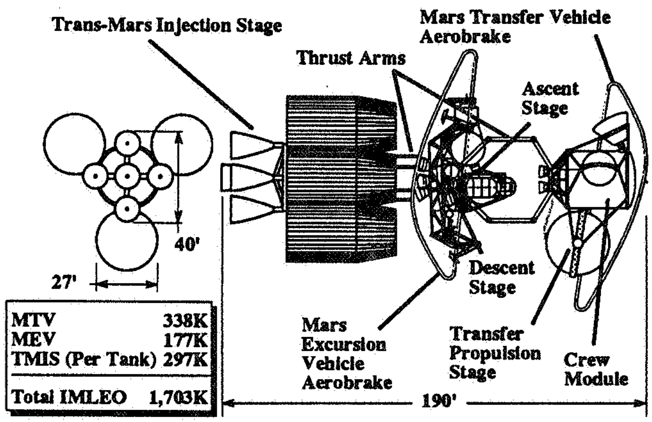


Figure 2. Mars Transfer and Excursion Vehicles

The mass requirements to S.S. Freedom to accommodate the Mars piloted outpost cover a range of approximately 1210K-1870K depending on the mission type and the year flown. Propellant for trans-Mars injection and trans-Earth injection constitute the majority of the mass to LEO.

Base and Expanded Model

A composite model of the projected range of mass-to-orbit requirements for the base and expanded (Lunar and Mars portions) programs is shown in Figure 3. Lunar mass delivery requirements more than double the total mass-to-orbit requirements by the turn of the century. When Mars missions begin in 2015, total mass delivery requirements more than double again. Figure 4 illustrates the number of individual payload elements delivered to LEO by payload mass range for the 1990 to 2020 time period. The payload mass range of greater than 65K (beyond the capability of existing space transportation systems) is a new requirement imposed by Lunar/Mars missions.

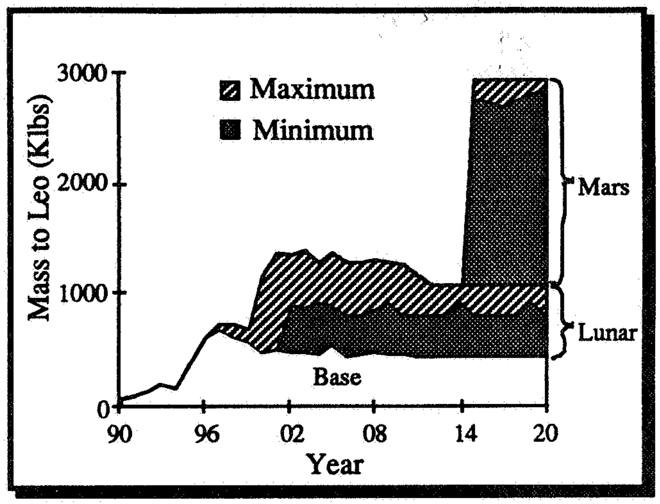


Figure 3. Composite Mission Model - Mass To LEO

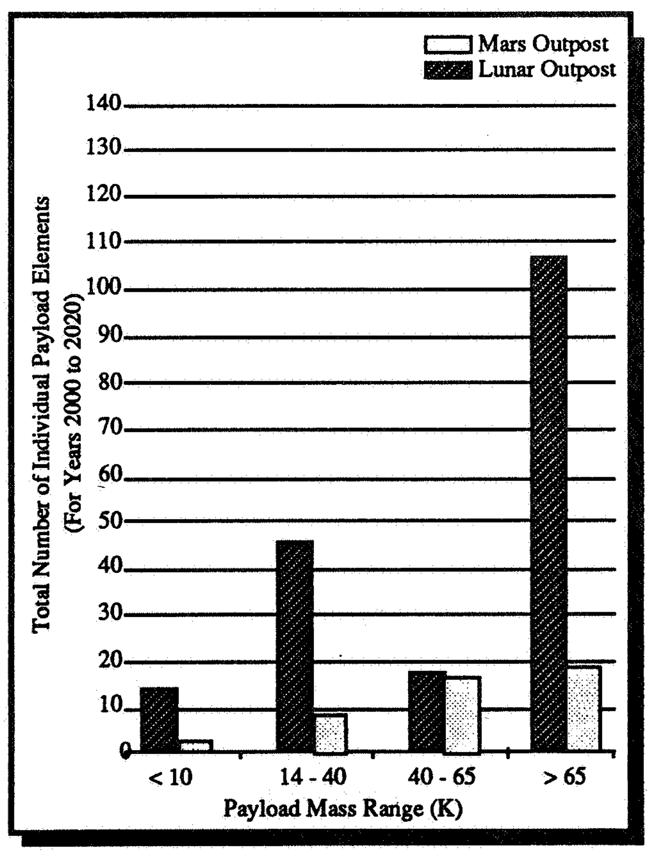


Figure 4. Composite Mission Model - Number of Payloads To LEO

Existing Systems

Earth to Orbit

EXPENDABLES. Three families of unmanned ELVs, Titan, Atlas, and Delta, are currently available to augment the STS. As shown in Figure 5, the capabilities of these ELV families have been enhanced over the past few years to meet increasing national needs. The Titan IV, Atlas II and Delta II are adequate to accomplish all robotic missions. Planned ELV flights through FY 1994 are shown in Table 3. Depending on total national needs in the time period of the robotic missions, Table 4 indicates a potential Titan IV launch rate problem (assumes continued Titan IV launches at the rates indicated). HLLV availability could alleviate ELV constraints by providing joint manifesting of some of these missions.

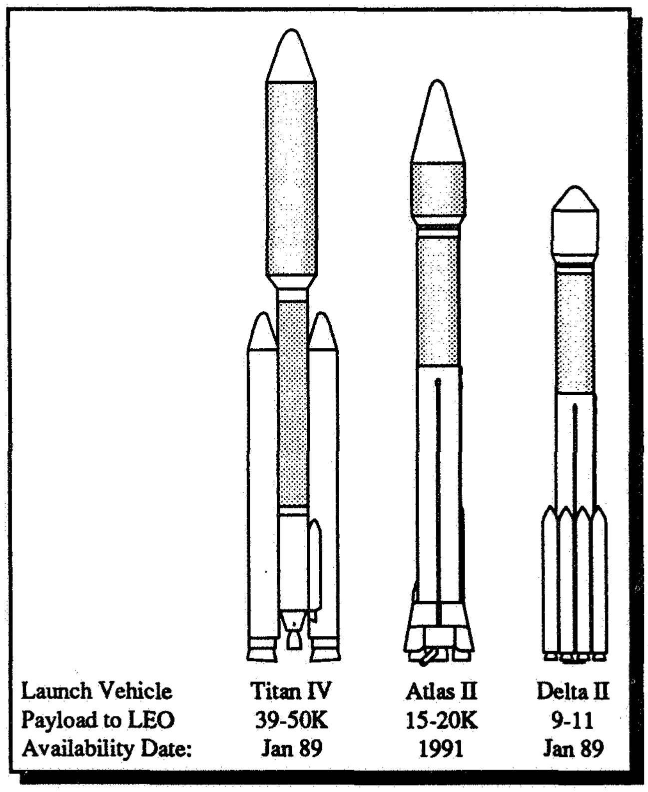


Figure 5. Expendable Launch Vehicle (ELV) Capabilities

Launch Systems	Flight Rates - Fiscal Years					
	1990	1991	1992	1993	1994	Total
Titan IV	5	7	5	6	5	28
Delta II	6	4	4	4	2	20
Atlas II	-	2	2	2	1	7
Totals	11	13	11	12	8	55

Table 3. Planned ELV Flights

New or Upgraded Transportation Capabilities

ETO Vehicles

By the mid to late 1990s, ETO transportation systems will require a heavy lift capability to support the new initiative missions. The only heavy lift concept being considered prior to 1999 is the Shuttle-C, an unmanned Shuttle derived cargo vehicle. The Shuttle-C could support assembly of S.S. Freedom and its growth to a Lunar transportation node. At the turn of the century, the expanded requirements of the Lunar/Mars initiative will necessitate greater capabilities of unmanned, low cost launch vehicles such as ALS or derivatives of the STS. Lunar outpost ETO transportation requires significantly higher launch rates and lift capabilities than are currently available and could utilize the Shuttle-C, ALS, or a mixed fleet of both. Growth HLLVs will be required to launch the payloads, propellants, and space vehicles required for the Mars outpost missions.

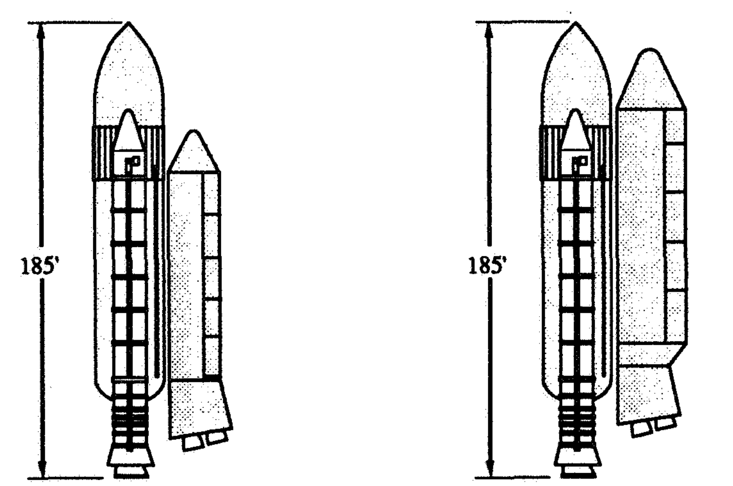
SHUTTLE-C. The Shuttle-C is designed to be an unmanned launch system capable of reliably delivering heavy payloads to orbit. Shuttle-C is not a new system, but rather an expansion of our current STS program. It uses existing and modified STS qualified systems, such as ASRBs and a slightly modified ET with structurally enhanced interfaces. To minimize ETO launches, the 15 ft and 25 ft diameter shrouds will be utilized with a common expendable boattail (Figure 6). Lunar missions can be manifested in three launches for the early missions and two launches for the steady-state missions. The 15 ft configuration (157K capability) maximizes propellant and high density payload delivery to orbit. The 25 ft configuration (135K capability) is required to accommodate delivery of the large diameter LEV and aerobrake elements.

The ETO transportation requirements for the Mars outpost require a launch vehicle with an expanded payload volume and greater lift capability than that required for the Lunar missions. The growth HLLV (Figure 6) is capable of delivering 300K to S.S. Freedom with a payload envelope of 40 ft diameter and 100 ft length. Four ASRBs are used as first stage boosters. Five SSMEs in a recoverable propulsion/avionics (P/A) module are used on a 33 ft diameter core stage. After main engine cut-off (MECO), the core stage separates from the payload and a small kick-stage transfers and circularizes the payload at the required orbit. Following core separation, the P/A module separates from the core vehicle and returns to Earth for reuse.

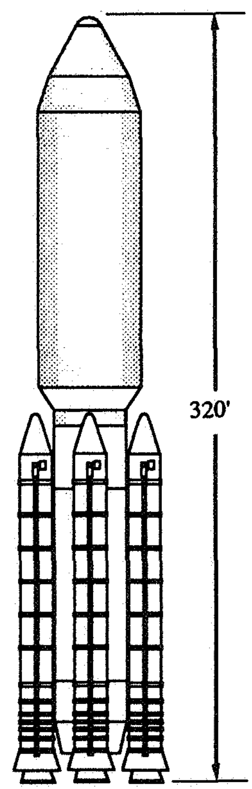
ADVANCED LAUNCH SYSTEM (ALS). The ALS, a joint program of the U.S. Air Force and NASA, is being defined as a family of unmanned cargo launch vehicles capable of accommodating a broad range of cargo size and mass. This system is being planned for the early part of the 21st century with the primary objectives of low cost per flight, high reliability, and high operability. A reference concept has been identified for initial deployment to meet the ALS requirements. The Lunar and Mars requirements have been evaluated as a delta to the ALS reference program.

To minimize Lunar HLLV launches, the two booster vehicle is used (Figure 7). Each Lunar mission can be manifested using two ALS flights. The payload weights shown are net payload to S.S. Freedom orbit with all circularization/stabilization and flight support equipment accounted for. In addition to the ALS vehicle, a transfer stage and uprated OMV are required to transfer the payloads from MECO to S.S. Freedom orbit. The most significant impacts of the Lunar initiative to the ALS program are those elements not currently in the program related to circularization/stabilization and the introduction of the two booster vehicle earlier than planned.

Lunar



Mars



Net Payload	157K
Boosters	2 ASRB's
Core Stage	Standard ET
Core Propulsion	3 SSME's
Payload Envelope	15' Dia.
	82' Length

Net Payload	135K
Boosters	2 ASRB's
Core Stage	Standard ET
Core Propulsion	3 SSME's
Payload Envelope	25' Dia.
	90' Length

Net Payload	300K
Boosters	4 ASRB's
Core Stage	New 30' Dia.
Core Propulsion	Recoverable P/A
	w/5 SSME's
Payload Envelope	40' Dia.
	100' Length

Figure 6. Shuttle Derived Vehicles for Lunar and Mars Mission Requirements

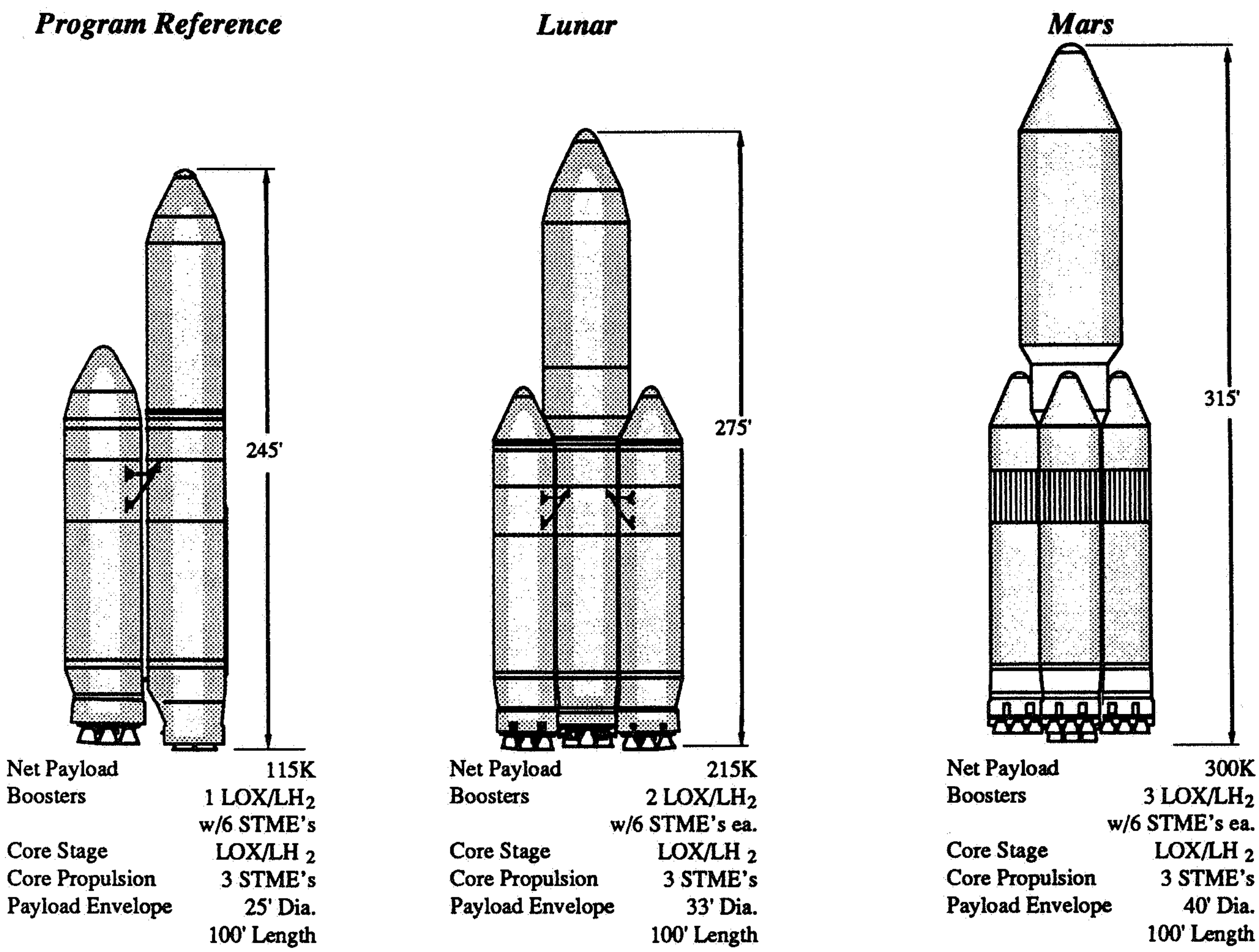


Figure 7. Advanced Launch System (ALS) for Lunar and Mars Mission Requirements

Mars missions are accommodated using previously mentioned vehicles together with the three booster vehicle shown in Figure 7. This vehicle, which utilizes a 40 ft shroud, will accommodate the large elements illustrated in Figure 2. The MTV configuration can be manifested within seven ALS flights.

Advanced Avionics Technologies

Figure 8 indicates the time period allowed to develop a launch vehicle to meet the requirements for the lunar missions. PDR for the launch vehicle needs to be held at the end of 1994. At this time the technologies that will be incorporated into this design must reach the OAST designated level 5. By CDR in 1995 the level must reach 6 or 7.

Figure 9 indicates the time period to develop a launch vehicle to meet the requirements for the Mars missions. PDR would be scheduled for 2005 at which time the technology maturity should reach level 5 and level 6 or 7 by CDR in 2008.

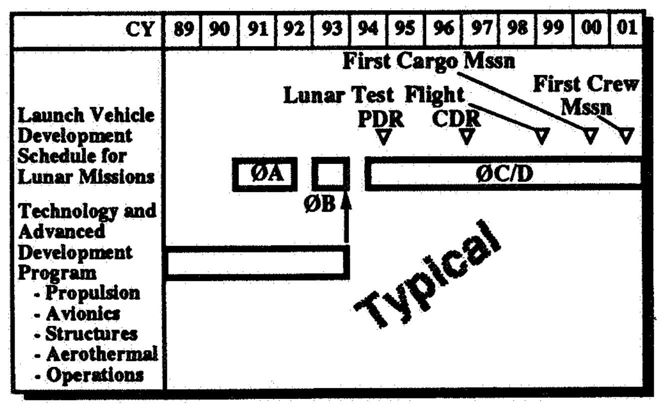


Figure 8. Launch Vehicle Development Schedule for Lunar Missions.

Since the launch vehicle for the lunar missions needs to be developed in the near term, the various technologies required for this vehicle will be the ones discussed in the following paragraphs.

Current launch vehicles were designed for performance, and incorporate the technology from their design era. They typically cost about $3600/lb of payload to orbit. Figure 10 shows we can reduce this cost for an HLLV

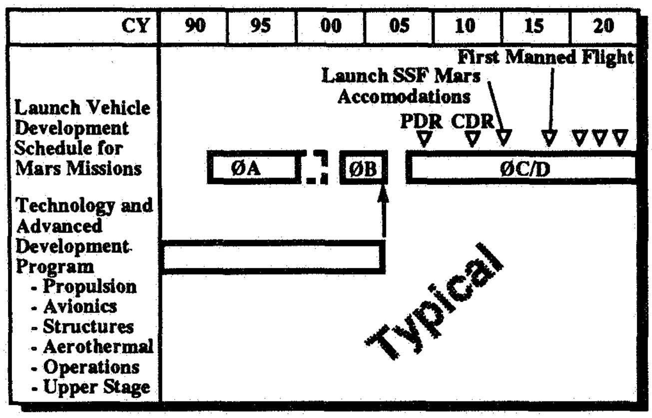


Figure 9. Launch Vehicle Development Schedule for Mars Missions.

payload by the economy of large payload capability, through the use of LO_2/LH_2 propellant to eliminate the need for a core second stage, and by rate and quantity effects to achieve less than $1000/lb before adding the advantage of technologies.

Further cost reductions for a new launch vehicle must come from incorporating appropriate new and applied technologies to reduce the recurring operations costs of manufacturing and launching. These are producibility improvements provided through new methods of manufacturing low cost engines, structures, automation of integration and launch processes, and higher reliability of the launch vehicle and its support equipment.

Figure 11 illustrates the cost of an existing technology "strawman" vehicle relative to current launch vehicles and the desired goal. The allocated cost difference to achieve the goal is shown for each technology area. This allocation was calculated using a sophisticated estimation and cost-savings software model that calculates technology savings and their synergistic effects (both positive and negative) upon vehicle/operations costs.

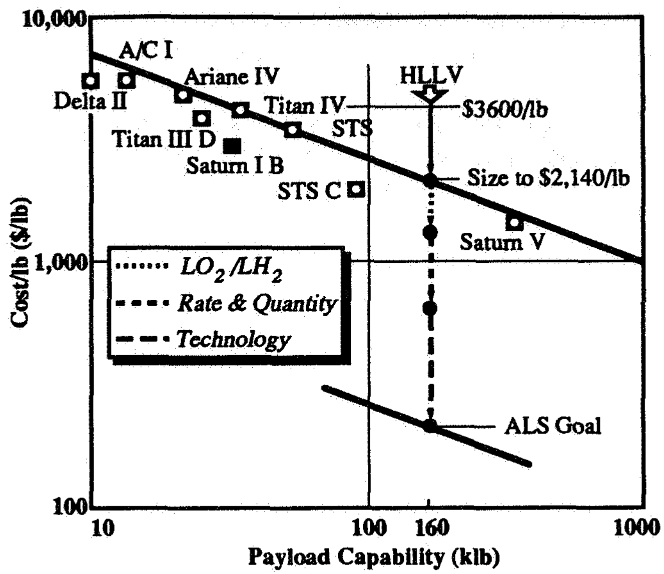


Figure 10. Identification of Target Cost Savings For Technology Developments

Figure 12 shows the degree of cost savings already achieved by technology demonstration/implementation on existing ELV programs.

Technologies have been ranked according to cost-reduction potential and consideration of their overall benefit to a new launch vehicle concept as shown in Table 4. The top nine in the list have the most significant cost savings.

The next grouping of two technologies have relatively lower cost savings but represent high schedule impacts.

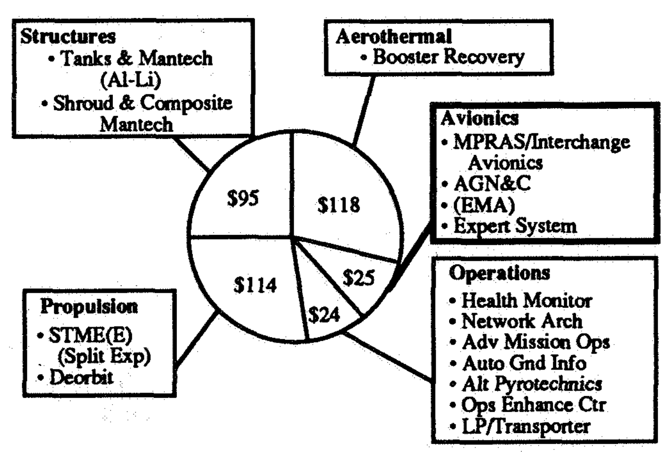


Figure 11. Focused Technology Contributes to Reducing the Cost to-Orbit

The next group of is generally ranked according to cost savings. Items like manufacturing technologies, or expert systems, make larger benefits available in other areas.

Items in the fourth group, of lesser cost impact, affect turn around times and resiliency to failures, and are important. The maturity of each technology at the present time is shown at the top of Figure 13. Definitions for maturity level are derived from the NASA Office of Aeronautics and Space Technology technique for describing the technology development process. Progressively increasing levels and maturity represent advancement from generic base to a focus on specific program needs.

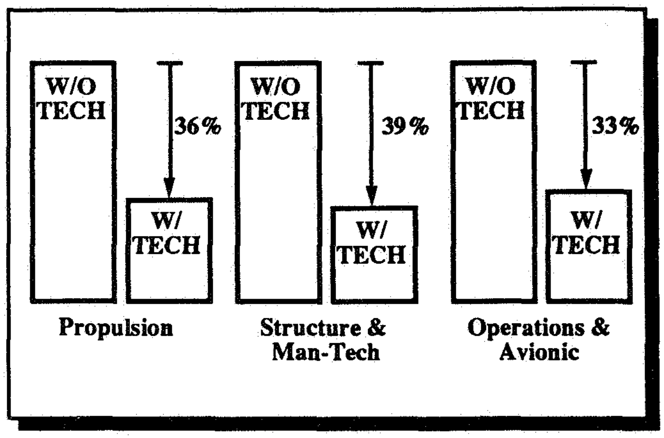


Figure 12. Projected Cost Savings for Each Technology Development Area

The avionics technology advancement must present an integrated approach to reducing launch system costs. Technologies are interrelated with each other and with the system development activity (see Figure 14). Interfaces between the various avionics elements within the vehicle segment and operations segment are recognized as big cost drivers. The different elements of avionics cannot be developed separately, then integrated, and provide any significant cost savings.

A multi-path redundant avionics suite (MPRAS) technology development is central to all launch vehicle avionics. All of the other avionics technologies, adaptive guidance, navigation, and control (AGN&C): electromechanical actuators with integrated electrical power supply (EMA): expert systems for decision-aid applications (ES): low-cost interchangeable avionics; and alternate pyrotechnics, exchange data with the MPRAS technology to achieve the benefits of an integrated approach. MPRAS, developed with an associated lab, can provide a test bed for demonstrating cost savings and technology feasibility.

Rank	Title	Contribution	Rationale
1	STME(E)-LO_2/LH_2 Gas Generator	Propulsion Cost	
2	STME(E)-LO_2/LH_2 Split Expander	Propulsion Cost	
3	STME(E) Vehicle/Engine Definition	Propulsion Cost	Major
4	Booster Recovery Module	Propulsion Cost (Booster Recovery & Eng Reuse)	
5	Expendable Tanks & Structures	Core & Booster Structures Cost	Cost
6	MPRAS	Cost & Enables AGN&C and Vehicle Reliability	
7	Integrated Health Monitoring	Operations Cost, Engine & Vehicle Reliability	Impact
8	Composite Payload Shroud	Shroud Structures Cost	
9	Interchangeable Avionics	Backup Avionics Cost	
10	Ops Facitilies Design-Ind Prep	Schedule-Preparedness for Assembly & Launch	Schedule
11	Launch Platform/Transporter	Transporter Cost and Schedule	Impact
12	Mantech-Automated Welding & NDE	Manufacturing Cost of Structures	
13	Operations Enchancement Center	Validates Ops Cost & Procedures	Enables & Validates
14	Expert Systems	Enables AGN&C, Health Mon, & Automated Ops	Other Technologies
15	Mantech-Composite Structures	Manufacturing Cost of Structures	
16	Advanced Mission Operations	Mission Planning Costs	
17	AGN&C	Mission Planning Cost & Vehicle Robustness	
18	Network Architecture	Ops and Facilities (Computer) Cost & Schedule	Lesser
19	Solid Rocket Booster	Backup Propulsion Cost and SRB Reliability	
20	Electromech Act/Power Supply	Operations Checkout Cost	Cost
21	Auto Ground Info Processing	Information Processing Costs	
22	Core Deorbit	Cost and Technology Risk Reduction	Impacts
23	Aero Data Bases	Supports Structure Cost Reduction	
24	Alternate Pyrotechnics Initiation	Operations Cost	

Table 4. Technology Prioritization Accounts for Cost and Risk Factors

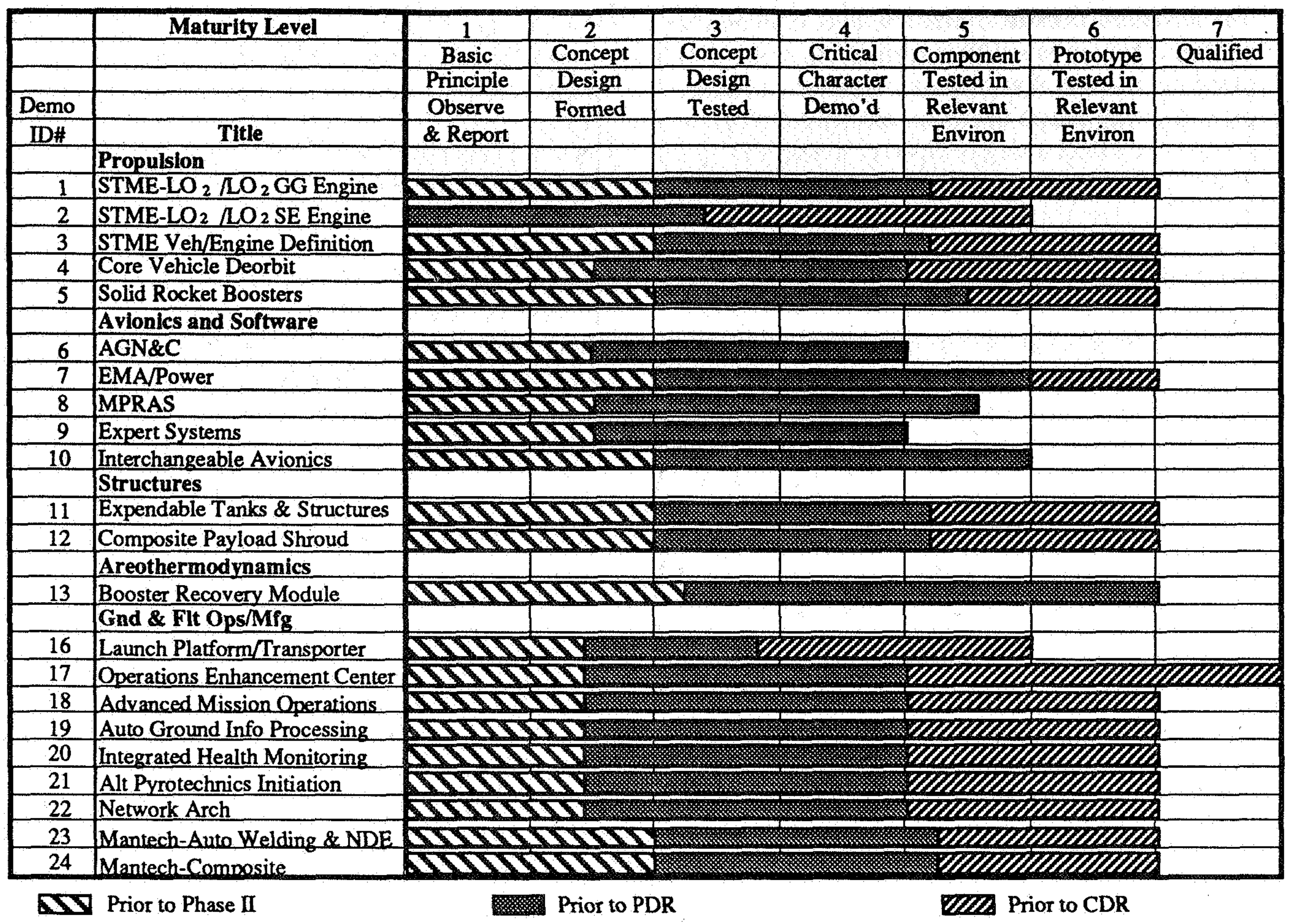


Figure 13. Technology Maturity Available by at least CDR.

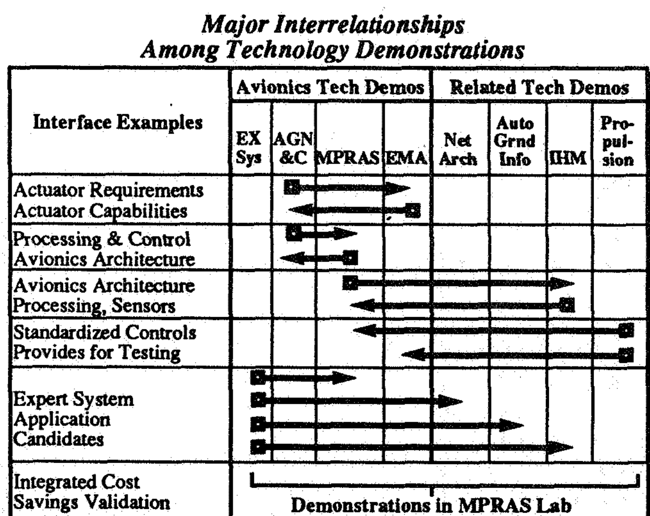


Figure 14. Avionics Technology Demonstrations Interact with Propulsion, and Opns Elements

Avionics technologies are included in ground and flight operations. These technologies are associated with automating information processing in the ground systems, more efficient facility designs, and development of a lower-cost launch platform/transporter.

Specific ground and flight operations technologies based on previous study results have been selected to achieve significant development cost or schedule reductions. These candidate technologies are shown in Figure 15, including their relationships with each other, and avionics and software technologies.

The entire ground operations system, including its manpower and facilities, should be optimized to support processing. Selected application of automation and robotics will further enhance operations.

The advanced mission operations goal is to reduce the off-line, but manpower-intensive, mission-peculiar planning to levels that support a standard mission. To provide timely and up-to-date information throughout the ground operations segment, the automated ground information processing technology development should develop electronic processing procedures and investigate and develop the electronic infrastructure to support their application.

The integrated health monitoring (IHM) technology is designed to reduce or eliminate the traditional test and checkout operations that require large manpower resources to perform and analyze procedures. With today's computing and correlation abilities provided by inexpensive electronic devices, the potential for cost reduction is enormous. IHM will also provide the resources to minimize post-failure stand-down. IHM must be built into all elements of the launch vehicle system, and, therefore, will be interacting with technology projects in all areas. IHM will provide requirements to ensure vehicle and operations systems will support the IHM architecture. Associated technology projects will feed system definition to IHM to allow its effective tailoring.

Finally, the network architecture and operating system technology area will tie the ground and flight operations systems together into an integrated system of networked computer workstations, that will reduce or completely eliminate the requirement for single-purpose special test equipment. Integration of operations system networks, automated information processing techniques will provide an architecture which supports highly efficient management and operations.

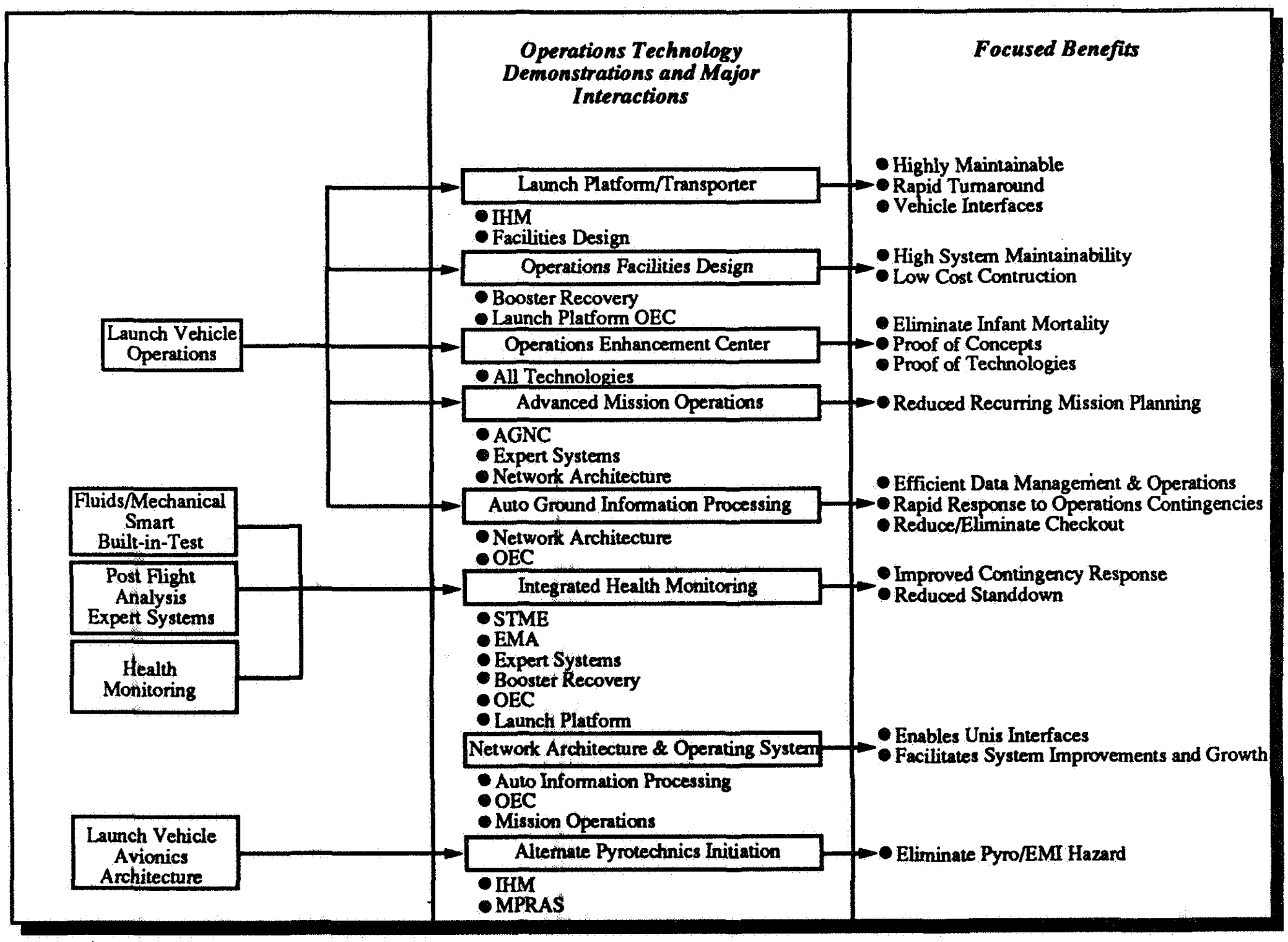


Figure 15. Operations Benefit Through Technology Focus and Integration.

Adaptive Guidance, Navigation, and Control (AGNC)

The objective is to develop a low life cycle cost (LCC), robust GN&C system and its integrated mission preparation system. One approach will be to automate as much of the interactive portions of the analysis as possible and provide a single integrated "package" (a work station environment) on which these tasks can be performed. This will reduce the cost and time associated with GN&C preparation for a new set of payloads/cargo for each mission. The other approach will be to make the on-board algorithms more sophisticated or adaptive so that they do not need as much preparation for a particular flight and can autonomously adapt to the unique conditions of each flight and payload. Both approaches have the goal of producing a GN&C design that is as robust as necessary. Such a system would be insensitive to all payloads/cargo combinations, weather and missions, and would never require mission specific analysis or changes. The preparation system and cost for such an ideal GN&C system would be minimal. Each approach would have to be measured to determine the breadth and depth of its preparation system and process. Robustness here is defined as a system's ability to accommodate new payloads/cargo or missions without changes. For example, a control system that can accept a payload weight range of 28,000 lb to 160,000 lb without any analysis or changes to any part of the GN&C system is more robust than a system that can only tolerate a range of 28,000 lb to 90,000 lb without changes.

Current costs of mission analysis for a unique payload are ten times the cost for re-flight of a similar payload to the same destination. From various analysis the flights in the model would carry a unique payload or a similar payload to a new destination. The use of AGNC will reduce the analysis task for any mission to less than that currently required for a re-flight. This gives the AGNC benefit shown in Figure 16. In addition, ground processing data has been analyzed and reductions in GN&C preparation that amounted to 10% of the overall ground processing task has been identified. The other potential benefit of AGNC, improved reliability, is not incorporated in the cost-benefit analysis.

Electromechanical Actuation (EMA) with Electrical Power Supply

An integral electromechanical actuation system coupled with an integrated electrical power supply (IEPS) system,

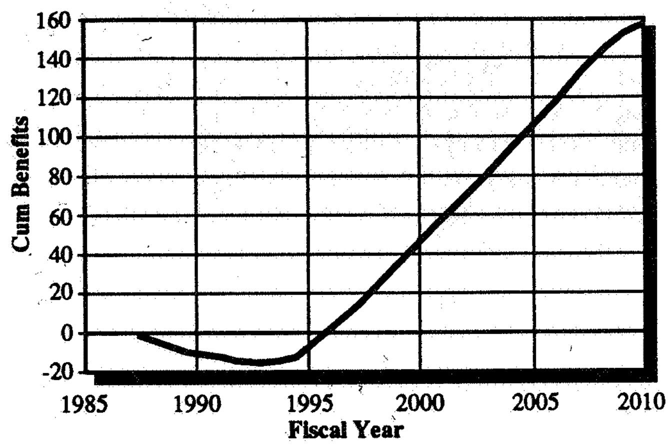


Figure 16. Adaptive GN&C Technology Cost Benefit Potential

can provide significant launch vehicle operations cost reductions. These cost reductions are attained through use of modular design, automatic checkout, and by the elimination of fluid actuation control.

EMA systems are being prepared as a viable alternative to the classic hydraulic fluid control approach. Previous trade studies indicate significant potential cost savings for launch vehicle applications. This is primarily due to the operational flexibility and minimum maintenance and support requirements associated with an EMA system. In addition, higher reliability, superior frequency response, simplified failure detection methods, and system adaptability to redundant design concepts are other advantages.

To successfully meet all the anticipated advantages of an EMA system, several key technology issues need to be resolved.

a. High-power motor/mechanical actuator design - While high-power assemblies have been used on ships and other terrestrial applications, we need to evaluate (and perhaps modify) the current designs for operation in the space environment and their ability to meet launch vehicle size, mass, and cost constraints.

b. The design of the high-energy power processors - These are required for either the electronic commutation of brushless DC motors, or the resonant processing for the three-phase induction motors. Along with the basic designs, we will require the supporting high-power component technologies that can be used to build the hardware.

c. High-density energy sources - The high peak-to-average power profiles common for EMA systems may require different energy storage and distribution options. Temporary energy storage in capacitors or different supplementary batteries may be required to minimize energy source mass and cost. The EMA/IEPS system is shown in figure 17.

POWER SOURCE. The primary power source must be able to provide continuous power from prelaunch activities through mission completion. Variations in peak power requirements during the mission will require a power supply concept to be robust and capable of supplying high energy rates on demand.

Power source technologies such as batteries (silver-zinc, lithium thionyl chloride) and other stored power sources (thermal and chemical) should be considered. Alternate power sources such as turbo alternators, gas generators, and auxiliary power units should also be evaluated. Power usage for more than 95% of mission time is approximately 55 amps/actuator. (There is a total of 20 actuators/vehicles.) However, during peak requiments-large EMA TVC activities-usage rate could exceed 150 amps/actuator. The 55 amps/actuator is based on an average actuator output power of 20 hp. The 150 amps/actuator is based on a peak actuator output of 50 hp. The above power is presumed to be provided at 270 Vdc. The 270 Vdc system is indicated for preliminary calculations only.

To accommodate these variations, options such as rechargeable energy storage capacitors and inductors or even thermal batteries could supplement primary batteries during peak energy usage.

Note that no new power supply technology issues need to be resolved for this type of application. However, technical issues for system integration, electromagnetic interference (EMI), thermal, and system performance concerns should be successfully demonstrated on a subscale basis for PDR to show confidence in the system concept.

Studies on prelaunch servicing and checkout tasks for ELV's and the Shuttle, shown in Figure 18, indicate potential savings of about 4000 hours for the ELV's and about 9000 hours for the Shuttle per launch, through replacing the hydraulic TVC and the pneumatic actuation system with an EMA system. The space shuttle data was obtained from Pan Am services which was under contract for shuttle processing. The ELV data was generated using GDSS launch cost data for the Atlas/Centaur.

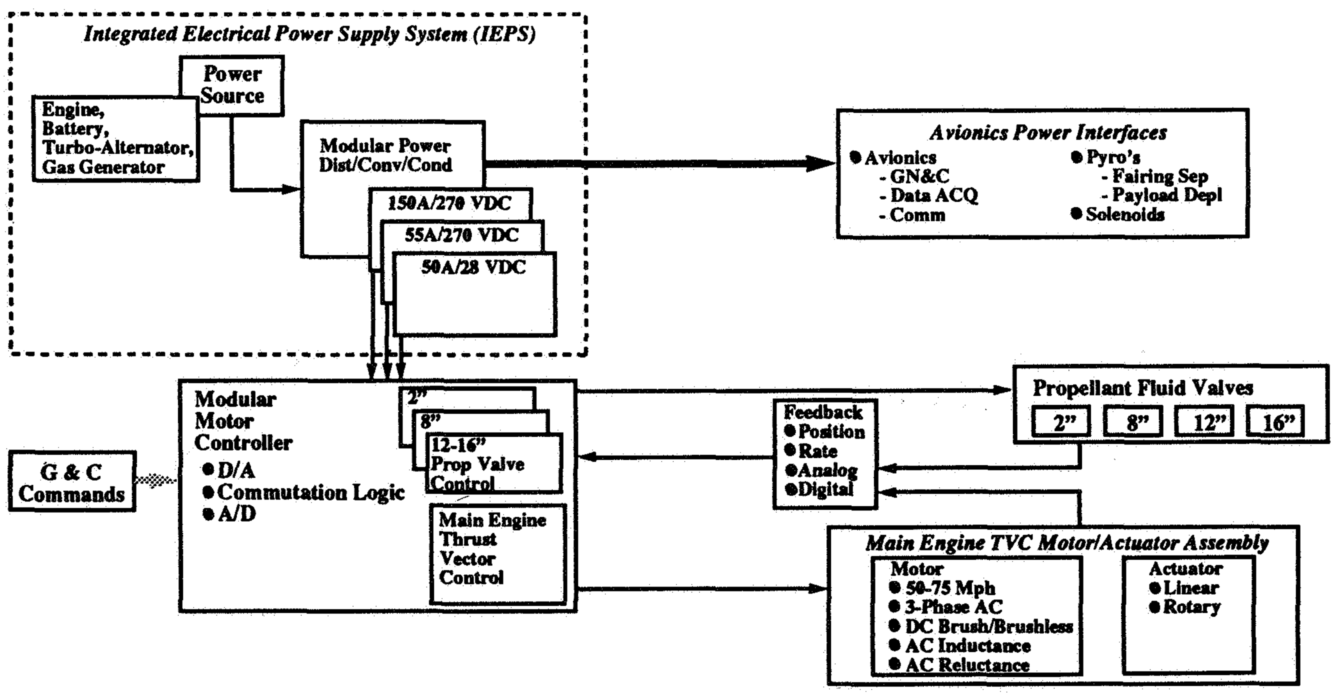


Figure 17. Alternate Configurations Assessment

The figures do not reflect EMA savings in the area of system fault isolation and corrective procedures when compared to a hydraulic system. Preliminary analyses show the TVC requirements to be similar to that of the space shuttle main engines (SSMEs), providing for potential saving of higher than 9000 hours per launch. Manpower savings are made in operations and ground support tasks. (*Replacing fluid actuation systems eliminates the need for regular and costly leak checks and contamination concerns.*)

The EMA system is sealed and storable. EMA/IEPS components are modularized and therefore easily replaceable. A requirement for complex ground support systems is also eliminated. The EMA/IEPS system will be independent and testable on demand, without a need for external support systems.

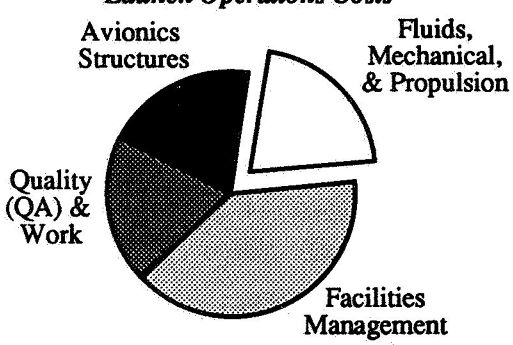
The ground processing benefits of EMA systems are realized by eliminating hydraulic and pneumatic systems. Studies of Centaur for Titan and Atlas/Centaur conclude that a 6% reduction in overall ground processing costs are possible. In addition, hardware savings and reliability improvements are probable. However, the cost-benefit analysis shown in Figure 19 excludes reliability improvements and includes only a small hardware cost benefit due to modularity and a philosophy of multiple subcontractor sourcing.

Multi-Path Redundant Avionics Suite (MPRAS)

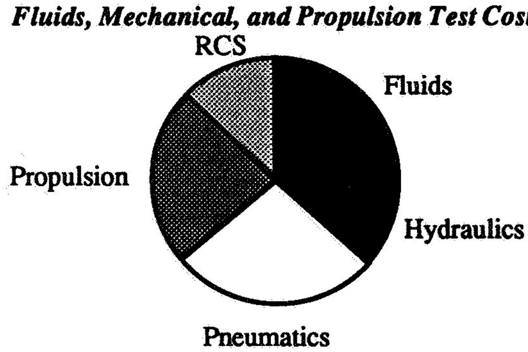
MPRAS provides the groundwork to integrate the entire airborne avionics system. It provides design standards that minimize life cycle and operations costs, while increasing reliability. The MPRAS architecture would make extensive use of bus techniques and common modules. Figure 20 shows a proposed architecture. It makes extensive use of busing techniques and common modules. Cost savings can be realized as shown in Table 5.

Potential Testing Cost Savings From Electromechanical Systems

Launch Operations Costs



Fluids, Mechanical, and Propulsion Test Costs



	HR	Savings Per Cent Used	Savings (HR)
Total ELV Launch Operations	91575		
Total F/M/P Test Time	19197		
Fluids	4928	10%	490
Hydraulics	2177	90%	1960
Pneumatics	5143	40%	2060
Propulsion	4616	20%	920
RCS	2333	<5%	0
			$\boxed{5430\ \text{HR}}$
Equivalent Shuttle HRS			
Plumbing, Vent, and Drain	1069	20%	210
Hydraulics	1573	90%	1430
Propulsion	10099	40%	4040
ACS	2099	<5%	0
VAB Activities			5670
Pad Operations (35%)			3600
			$\boxed{9270\ \text{HR}}$

Use of Electromechanical Valves and Actuators Can Reduce ELV Test Time by >5000 HR, and Potentially >9000 HR for the Shuttle or ALS.

Figure 18. Operational Cost Savings Derived From EMA Applications.

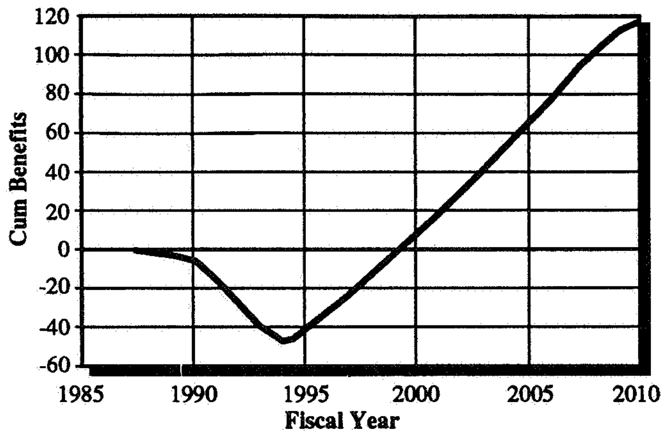


Figure 19. EMA Cost Benefits Potential

Future launch vehicles could include core and solid boosters or core with liquid boosters(s). To provide the processing required, a flexible architecture is paramount. Conventional triple modular redundancy (TNR) systems must be sized for the worst case. Growth potential must be planned to preclude the redesign of more complex vehicles and to maintain a simple integrated checkout concept. The flexible MPRAS architecture will provide the ability to add or delete liquid booster interfaces from the system as required and will be scalable to manned vehicles. One example of conventional design is point-

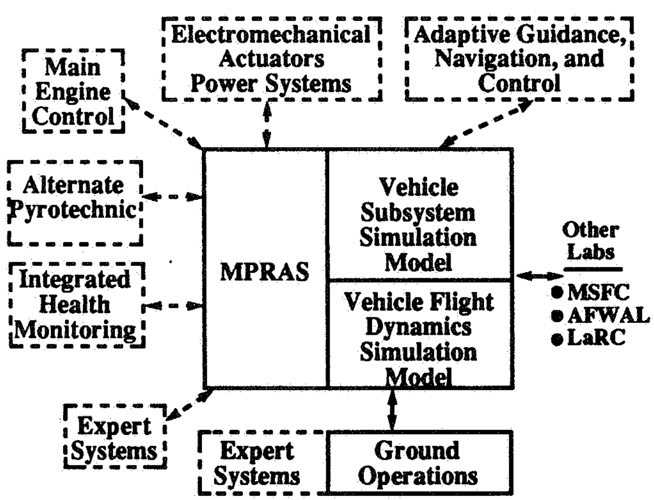


Figure 20. MPRAS: Integrated Avionics Approach To Reduce Costs

to-point harnessing, which can be reduced significantly with an appreciable cost reduction. The Centaur on Titan has approximately 100 yard-wired functions wired the entire length of the vehicle. A bus could reduce this harness by an order of magnitude.

Cost Savings Concepts
• Reduction of Hardware Cost
- Common Modules
- Standard Interfaces
- Use of Data Buses
• Increased Reliability
- Self-Test Modules
- Redundancy
- Reconfiguration
• Reduction of Operations Cost
- Automatic Checkout
- On-Board Data Processing
- Mission Planning
- Mission Analysis

Table 5. MPRAS Concepts Potential

A strawman MPRAS architecture that can be used as a point of departure is shown in Figure 21. The method of reducing launch vehicle life cycle cost is first to reduce hardware cost and improve reliability. This is done with very reliable common modules using standard interfaces and software produced in large quantities. For example, the common module processor may be used for guidance, signal processing, or as the engine controller, which reduces the number of unique processors in the system. This will reduce the number of avionic units required and with standardized back planes and buses, upgrades and expanded capability are possible, all producing cost savings. Also, the design is simple, reducing the complexity and increasing reliability.

Meeting the reduced operations cost goal is available through the additional processing of the MPRAS architecture. The cost reduction can be achieved by reducing the manpower required for launch support in the areas of propellant loading, health monitoring, avionic monitoring, calibration, and data evaluation.

A cost benefit analysis is shown in Figure 22. The major contributor to the cost savings is the avionics hardware cost reduction. This hardware reduction comes from the reduced amount of hardware required due to MPRAS and the lower cost of parts due to standardization and multiple sources of suppliers.

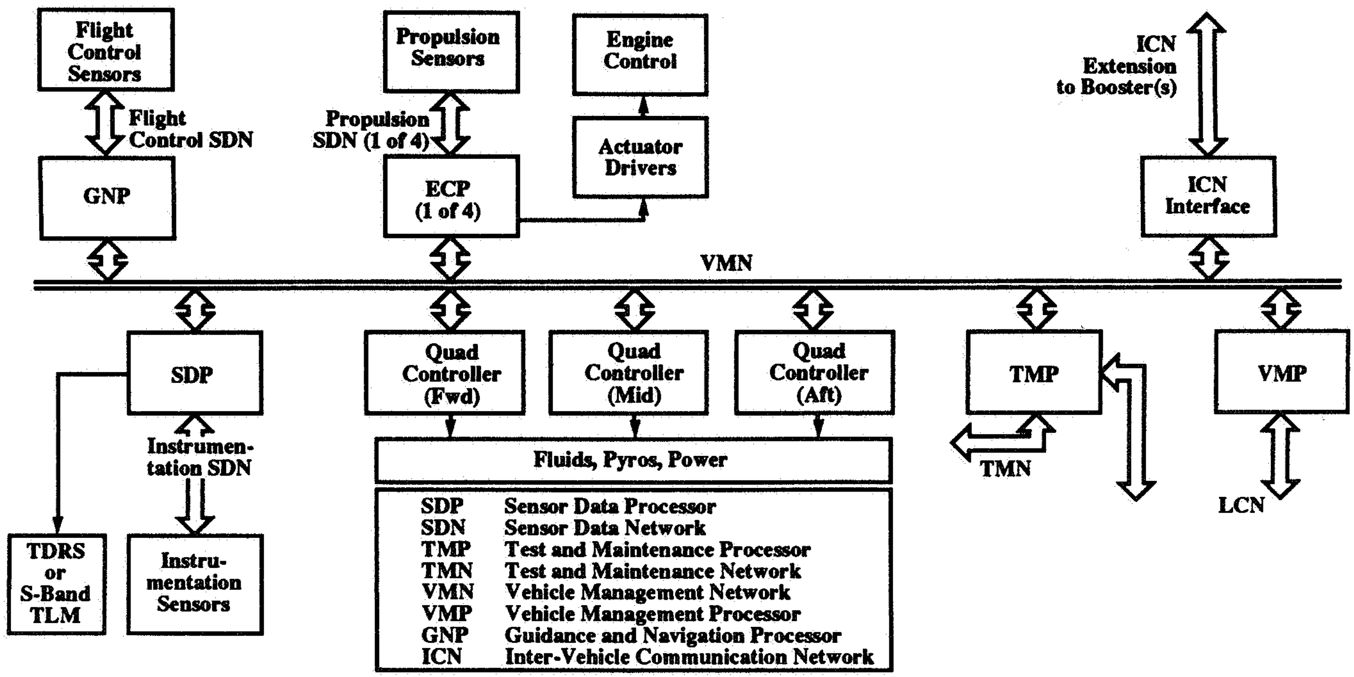


Figure 21. Distributed Architecture for Advanced Launch Vehicles.

Expert Systems for Decision-Aid Applications

Expert systems using artificial intelligence approaches provides effective individual and coupled decision aids for improved ground and on-board system autonomy and can reduce life cycle costs through efficient use of manpower.

Future launch vehicle program need to approach vehicle processing differently from in the past. Ground segment operations have been traditionally manpower-intensive.

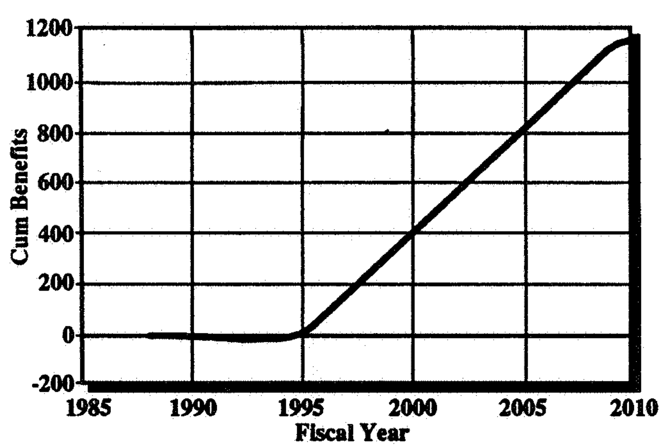


Figure 22. MPRAS Cost Benefits Potential

This is due to the many necessary checkout and prelaunch monitoring procedures that are set up and performed manually. Current pre-launch operations of expendable vehicles require a critical path of months will require a systematic approach to the automation of the ground operations to cope with the short turnaround processing schedule proposed.

An expert decision aid is a software approach to solving particular problems that are constantly changing and complex or adaptive in behavior, the opposite of an analytical problem that is basically deterministic. Examples of these types of problems are the re-scheduling of a vehicle checkout due to a damaged cable or determining if a system is indeed faulty given conflicting sensor readings. These heuristic problems require a depth of knowledge and experience (art rather than science) to form solutions quickly. Expert systems embody that collection of knowledge and experience in modular pieces that are rules and facts that describe the proper thought process for a given SE for circumstances arrived at by any path. It is this modular independence that makes expert systems attractive. The incremental improvement of knowledge and experience can be built and tested readily without re-testing the rest of the software system, unlike conventional software that is difficult to maintain in a day-to-day changing environment.

Experience from launch vehicle programs and past studies have shown that there are many opportunities in operations that reduce costs and improve autonomy, including:

- **Ground operations:** daily planning support and timely work-around decisions aids
- **Ground checkout:** autonomous procedural operations and control, standard trends, and redline monitoring
- **On-board systems:** monitoring, integration, and control recommendations
- **Launch day:** fly with fault diagnostics and decision aids
- **Postflight:** data reduction and analysis

Figure 23 shows that decision aids have the most potential for application cost savings in the Ground Segment (checkout, logistics, preparation, and maintenance) and the Control Segment (mission peculiar, mission planning, and mission control). The Control Segment has been further broken down into seven costs areas and estimates were made for the expert system savings anticipated in each.

Low-Cost Interchangeable Avionics

The goal of this technology development is to significantly reduce the cost of producing critical avionics components by specifically addressing relaxation of the stringent restrictions typically placed on performance-driven units, and promoting standardization between units.

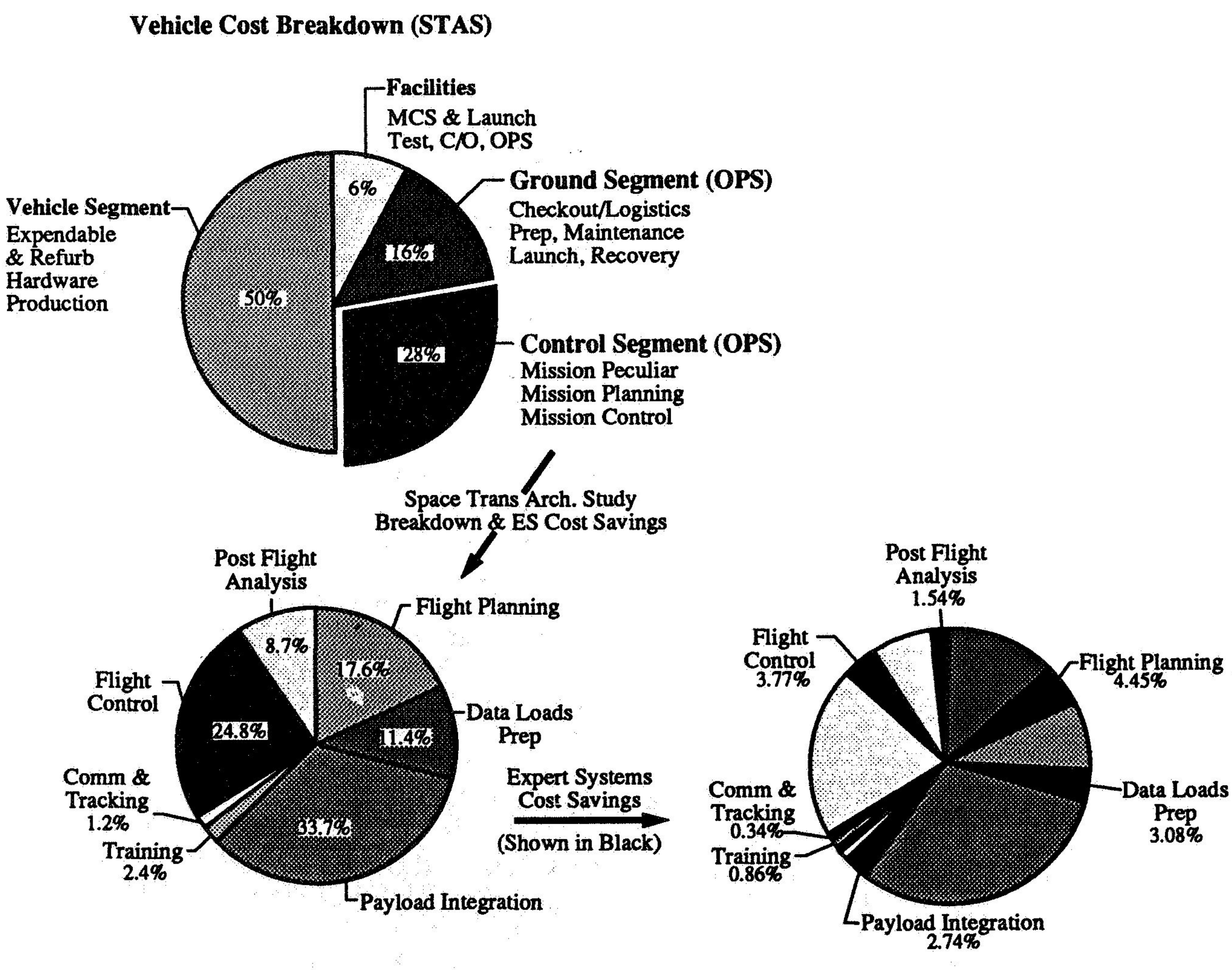


Figure 23. Decision Support Applications Contribution To Cost Benefits.

Figure 24 shows a proposed modular Inertial Navigation Unit (INU) with typical standard modules.

One of the primary goals of a new launch vehicle program is to significantly reduce the cost of putting a payload in low earth orbit. This goal is being pursued using the philosophy of a large, robust, highly-margined design. Because of this philosophy, the avionics size and weight are less critical to the overall vehicle performance. Also, the environments for the avionics packages can be made significantly less severe than for current launch vehicles. This is because the relatively large size of this vehicle allows for the placement of avionics packages in locations which have mild vibration, shock, and thermal environments.

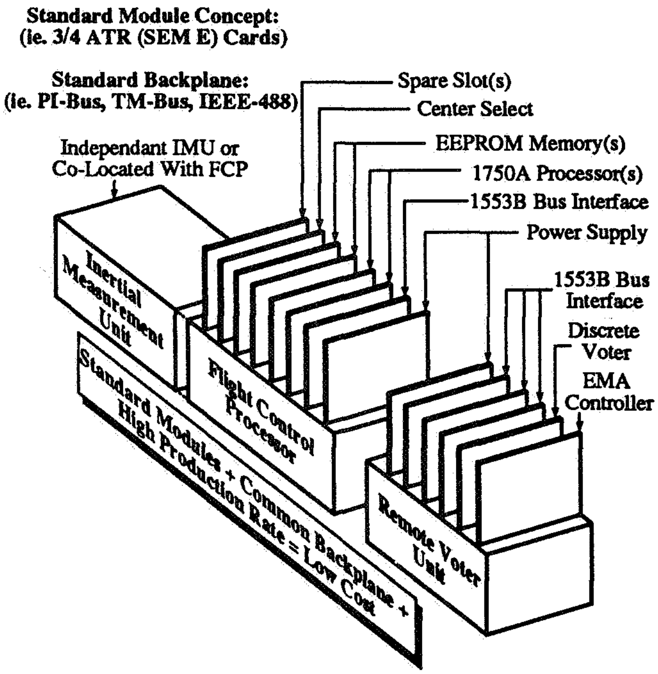


Figure 24. The Standardization of Common Processing Modules and Common Backplane

The relaxed environments allow for acceptable performance by using lower-cost instruments. For example, accelerometer capability is directly related to vibratory inputs, and gyro performance is heavily influenced by temperature extremes. By reducing these environmental extremes, performance requirements can be met at significantly reduced cost.

Automated Ground Information Processing

The objective of this technology development is to achieve cost savings through automation of key functions and interfaces in ground information processing.

The development should focus on creating an integrated paperless environment that ties together planning, procedure changes, quality assurance report (QAR) generation, and calibration tracking. This type of automation would ensure that the goal of providing short times between launches can be achieved.

Turnaround time requirements between launches demands streamlining operations to meet planned mission models. The approach for this technology development is to identify those areas in the ground operations cycle that can use automated information processing to provide cost savings and schedule enhancement. Figure 25 depicts an operations functional flow for a new launch vehicle program. While showing the entire operations functional flow, the figure separates the support and integration functions, and the control checkout and display functions. As illustrated, the support and integration function relies on input from the engineering design process and, through planning/scheduling and flow control process interfaces across the spectrum of ground operations.

One methodology would be to identify those functional interfaces that will provide the highest cost payoff by shortening delays in schedule during launch vehicle preparation. Current estimate indicates that the the two areas under "Preflight and Recurring Support," payload integration and engineering support, benefit significantly from automation. Three specific areas to analyze are: 1) procedures which include tracking and incorporating changes, 2) planning, and 3) calibration tracking. Associated with the planning process and procedures are the generation and disposition of QARs. Automated QAR disposition, with an emphasis on reducing the time required to work the QAR and hence, shortening delays in vehicle processing should be investigated.

Integrated Health Monitoring

An Integrated Health Monitoring (IHM) architecture design provides an automated means of observing the functional condition of critical vehicle hardware not only during flight, but also during production and ground

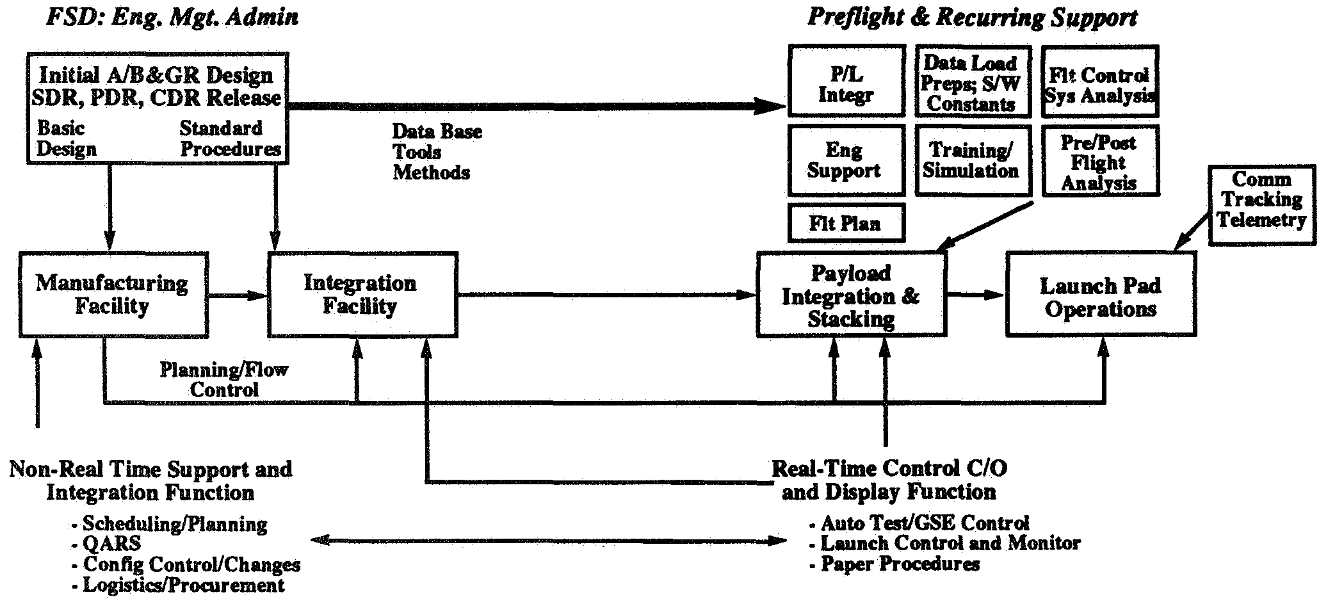


Figure 25. The Operations Function Flow Identifies Automation Opportunities.

operations. To achieve the high launch rate and low cost goals of advanced vehicles it will be necessary to identify, locate, and correct vehicle and ground support equipment hardware problems quickly without sacrificing reliability. IHM serves as a detection, diagnostic, and analysis tool to accomplish the program goals.

IHM provides quick, efficient, and thorough automated checkout procedures for vehicle and ground operations. If a hardware problem is detected, IHM will diagnose the problem to its source and serve as an analysis tool by which a user can automatically search a historical database for reference information. This capability will allow operators to focus their time and attention on the problem and resolution without having to sort through large quantities of nominal data.

All subsystems are affected by IHM as shown in Figure 26. The IHM concepts and ideas generated in the technology development can be to all vehicle subsystems for maximum efficiency and improved reliability.

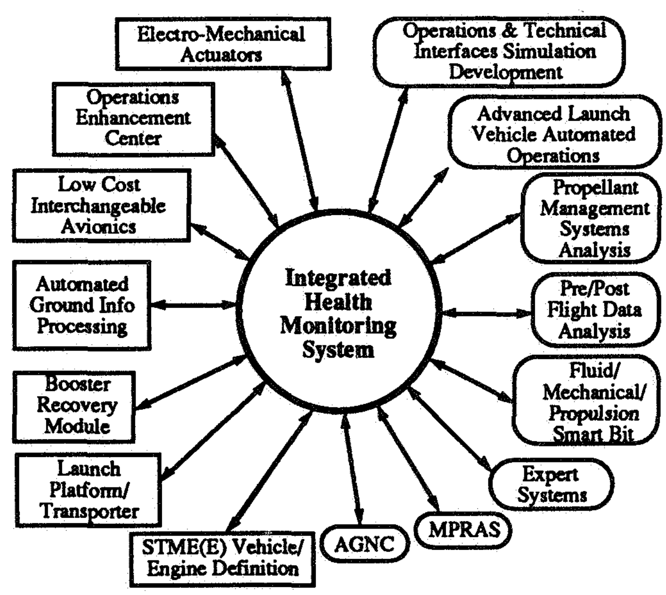


Figure 26. Representative Flow of Launch Vehicle Areas and IHM Concepts.

As an example, since rocket engine designs require such a long lead time before the initial vehicle itself, other subsystems that interface with the engine must be investigated (e.g., fluids flow) as well as the engine itself before design decisions concerning health monitoring can be made. By integrating "overall" IHM systems concepts and ideas with engine manufacturers' requirements early in the program, this will reduce problems that have occurred in the past with non-integrated health monitoring systems in the vehicle and ground operations areas. It is important that during the technology development all personnel know how the subsystems are interfaced to each other because of their interdependence (e.g., avionics control and feed system connections for the engine). This IHM philosophy ensures that all health monitoring design concepts remain

consistent and tolerant of any vehicle or ground operations design changes that may occur.

"Integrated Health Monitoring is defined as an automated means of verifying the operational status of all critical hardware associated with vehicle assembly, launch, and support phases of operations. IHM is able to verify initial subsystems, detect abnormal performance and impending failures, and identify suspected components." Thus, a health monitoring system is required not only on the vehicle, but within the production and ground operations areas as well. Figure 27 shows a diagram of the overall IHM system and its relationships.

A cost benefit analysis has shown that IHM provides a life-cycle cost benefit of $435 million compared to current methods within the production and ground operations areas, for an initial investment of $22 million for this program. Figure 28 shows the time-dependent benefits curve for IHM compared to current methods of health monitoring.

Network Architecture and Operating System

The objective is to develop technology related to network architecture and the operating systems that supports pre-launch, launch and post-launch activities.

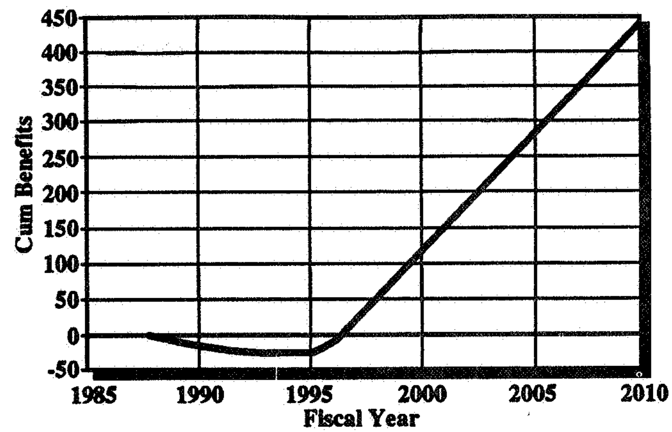


Figure 28. IHM Cost Benefits Potential.

By increasing the use of automation in the checkout and test of the vehicle and ground systems and post test data analysis, the cost of these operations can be reduced. It is crucial that the backbone network architecture and launch control system and its network architecture be defined in the early phases of technology development. Early definition of the backbone and launch control networks are critical to insure proper selection and to maintain low cost and schedule risk. Figure 29 shows a preliminary concept for the backbone network, that ties together all site elements.

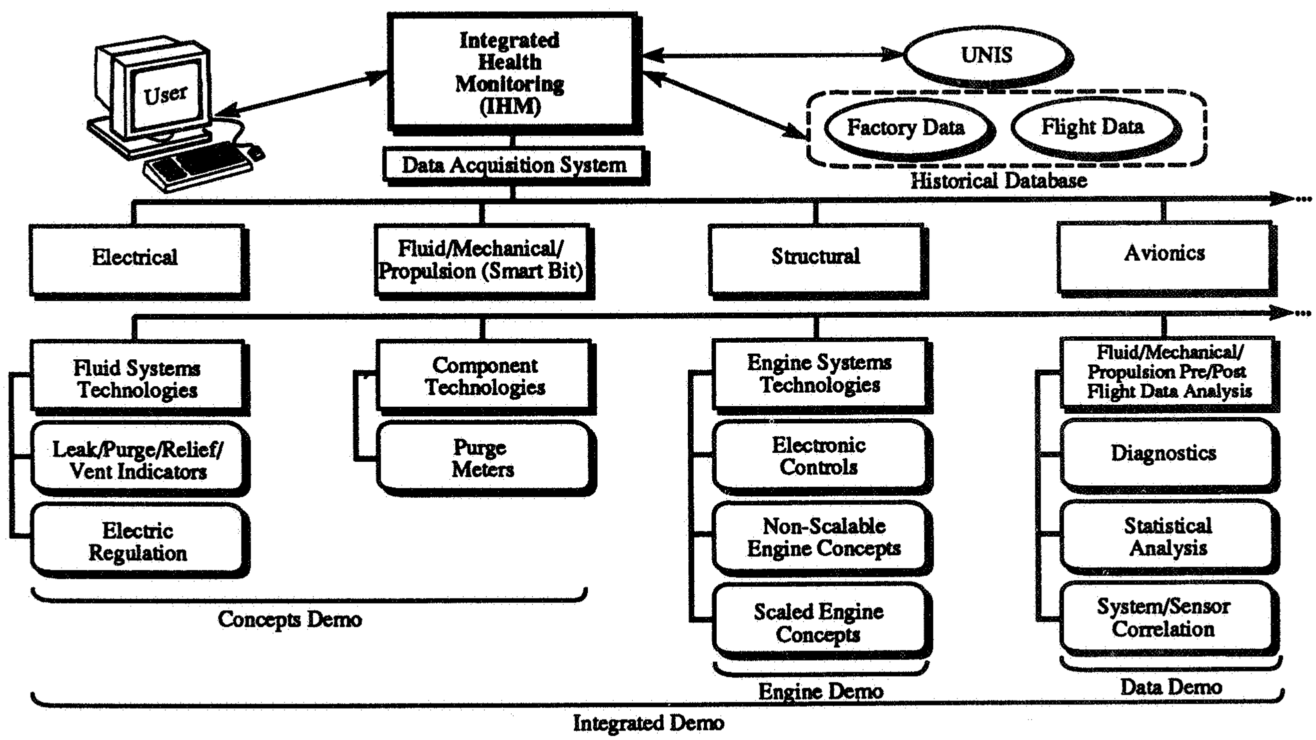


Figure 27. IHM Technology Development

Figure 30 shows a priliminary concept of the launch control network. The Network Architecture is the critical subsystem within the Ground Segment necessary to successfully integrate the elements for automated ground processing and launch operations.

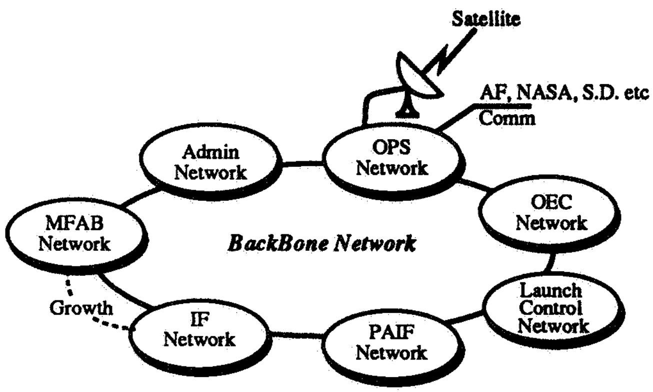
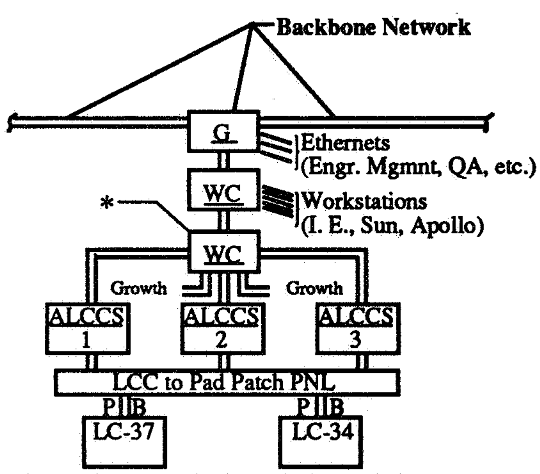


Figure 29. A Preliminary Concept for the Backbone Network.



Preliminary Concept of a Launch Control Network

WC	Wire Center/Concentrator (Fiber or Wire)
G	Gateway (Interoperable Connection Between Networks)
ALCCS	Advanced Launch Control Computer System
P	Primary Secure Comm Link
B	Backup Secure Comm Link
*	Provides Disconnect From Network and Connectivity Between ALCSSs During Critical Real-Time Operations

Figure 30. A Preliminary Concept for the Launch Control Network.

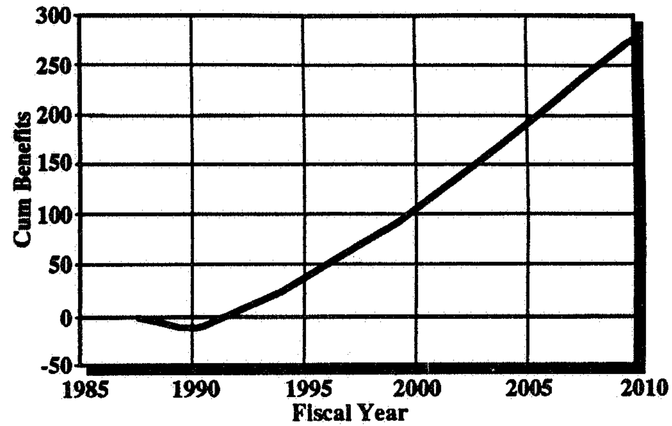


Figure 31. The Network Architecture and Operating System Operations Benefits Potential.

Experience has also demonstrated the need for a unified approach to automation in order to obtain the maximum cost savings.

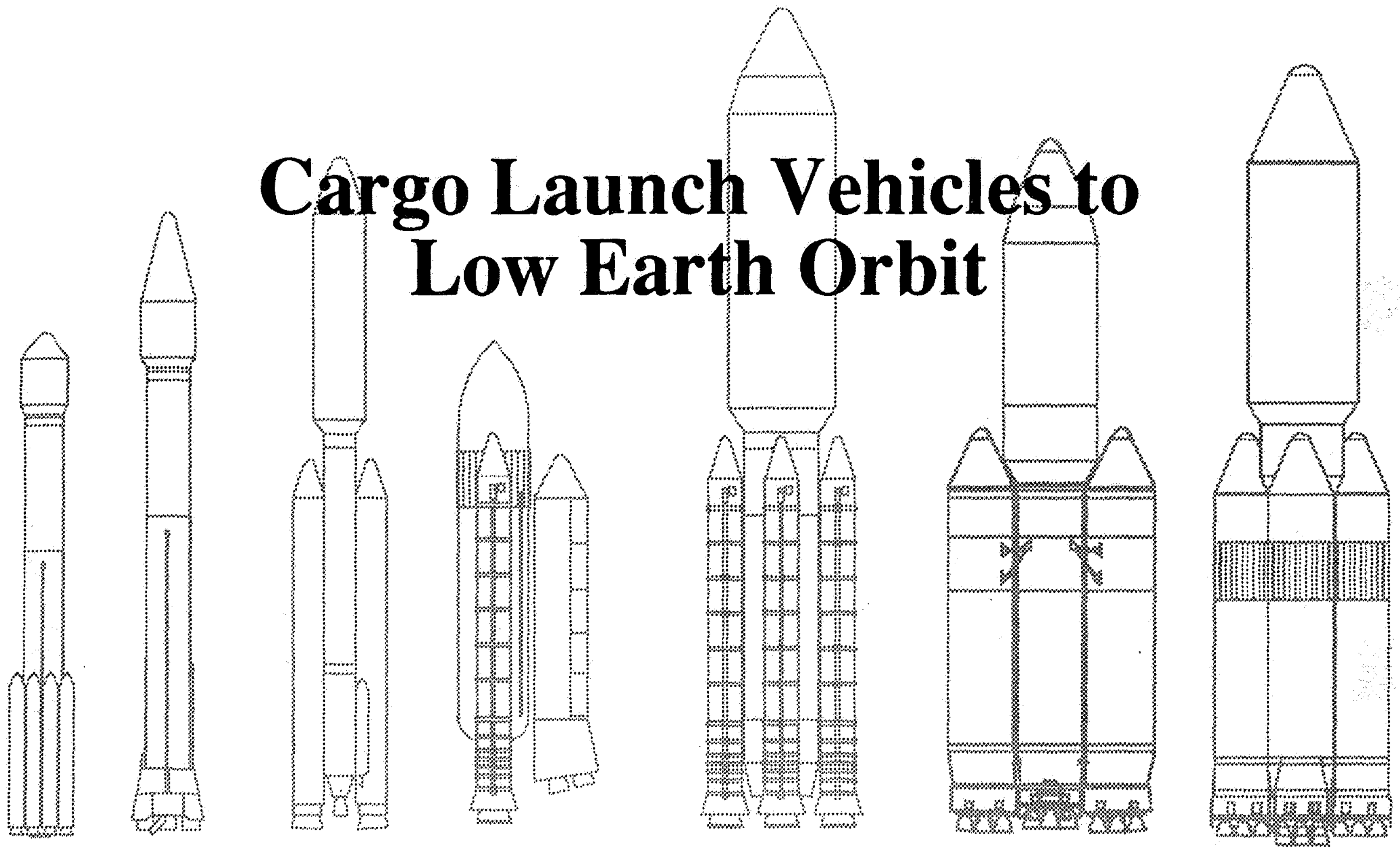
The cost benefit analysis shown in Figure 31 indicates a potential for significant cost savings.

Technology Transfer to Current ELV's and Commercial Launch Vehicles

Most existing ELV programs are committed to develop and implement cost saving technologies, thus they can develop and enhance the benefits of advanced launch vehicle technology development. These enhancements are enabled through, 1) in-house funded technology programs aimed at cost and turnaround savings that can be used as the building blocks for advanced launch vehicle technology development, 2) completed analysis and planned product improvements, which show that many of these technologies can be used on existing launch vehicle systems with minor impact to flight hardware, and 3) targeting some technology demonstrations for existing ESMC operations to prove these technologies and cost savings in comparison with current operations. In addition, new ELV systems have planned to incorporate some of these technologies.

Commercial launch vehicle programs do not develop new technologies because of the cost involved. They do plan to incorporate new technologies as they become available where it has been shown there is a substantial benefit in both hardware cost and particularly in operations costs.

Cargo Launch Vehicles to Low Earth Orbit



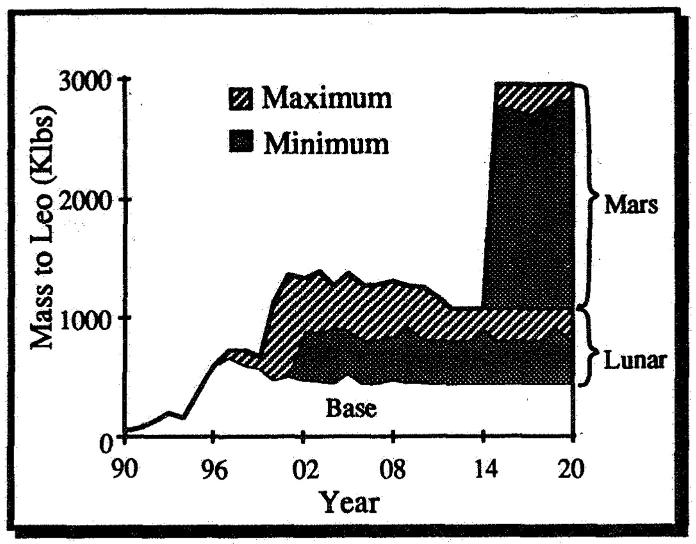
Robert E. Austin
Director, Space Transportation & Exploration Office
Program Development
George C. Marshall Space Flight Center

Cargo Launch Vehicle to Low Earth Orbit

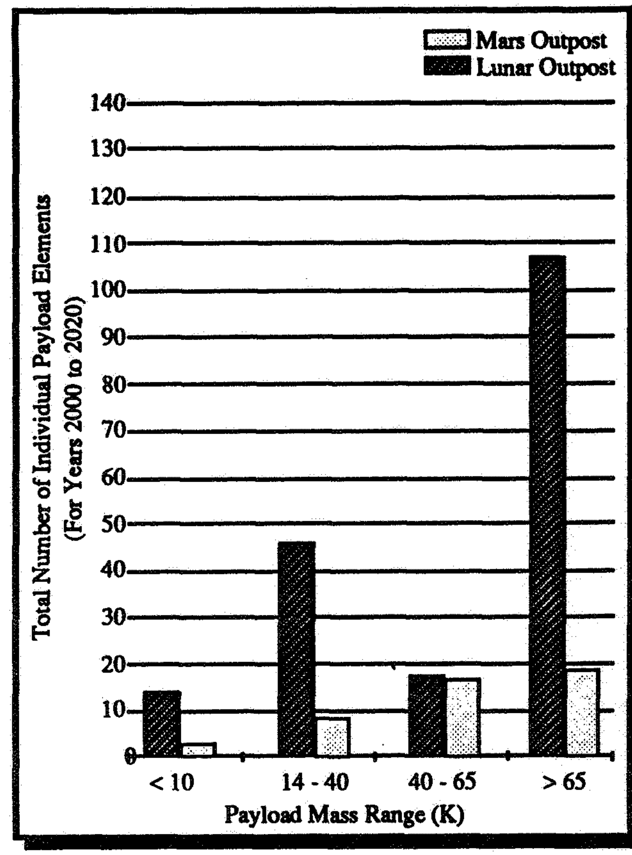
Briefing Topics

- Requirements for Cargo Launch Vehicles
- Cargo Launch Vehicle Concepts
- Avionics Technology Needs
  - Justification
  - Priorities
  - Interactions with Other Vehicle Areas
- Specific Avionics Technology Areas
  - Multi Path Redundant Avionics Suite (MPRAS)
  - Integrated Health Monitoring
  - Interchangeable Avionics
  - Expert Systems
- Technology Transfer
  - Expendable Launch Vehicles (ELV)
  - Commercial Launch Vehicles
- Summary

Composite Civilian Mission Model



Mass to LEO



Number of Payloads to LEO

Utilization of Cargo Launch Vehicles

Earth-To-Orbit Launch Vehicle	Civil Mission Requirements: Base				Expanded		
	SSF Assy/Logistics	Spacelab	Science/Planetary/ Observatories	SSF Accommodations	Precursors	Lunar	Mars
Existing:							
• Atlas					x		
• Delta					x		
• Titan			x		x		
• STS	x	x	x	x		x	x
New:							
• HLLV					x	x	
• Growth HLLV							x

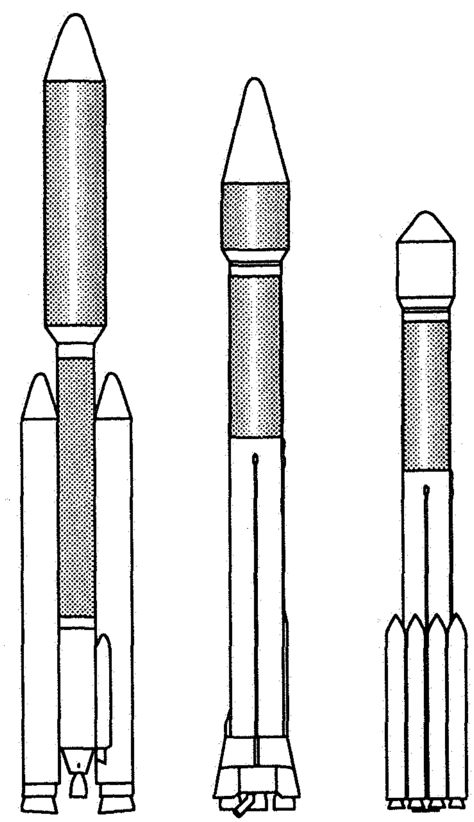
ETO Requirements

Destination	Mission (Flights)	Vehicle
Polar Orbit	Life Sat (10*)	Delta II
Lunar	Lunar Observer (2)	Atlas II
L_2 (Far Side)	Comm Sat (1)	Atlas II
Mars	Global Network (2)	Titan IV
Mars	Sample Return/ Local Rover (2)	Titan IV
Mars	High Res. Imaging/ Comm Orbiter (2)	Titan IV
Mars	Rovers (1)	Titan IV
Mars	Rovers (1)	Titan IV
Mars	Rovers (1)	Titan IV
Mars	Communication Sat. (1)	Titan IV

Note: *Two flights per year for five years.

Robotic Precursor Missions

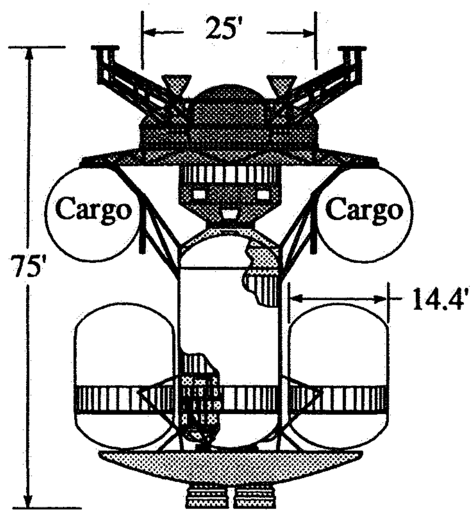
Expendable Launch Vehicles (ELV)



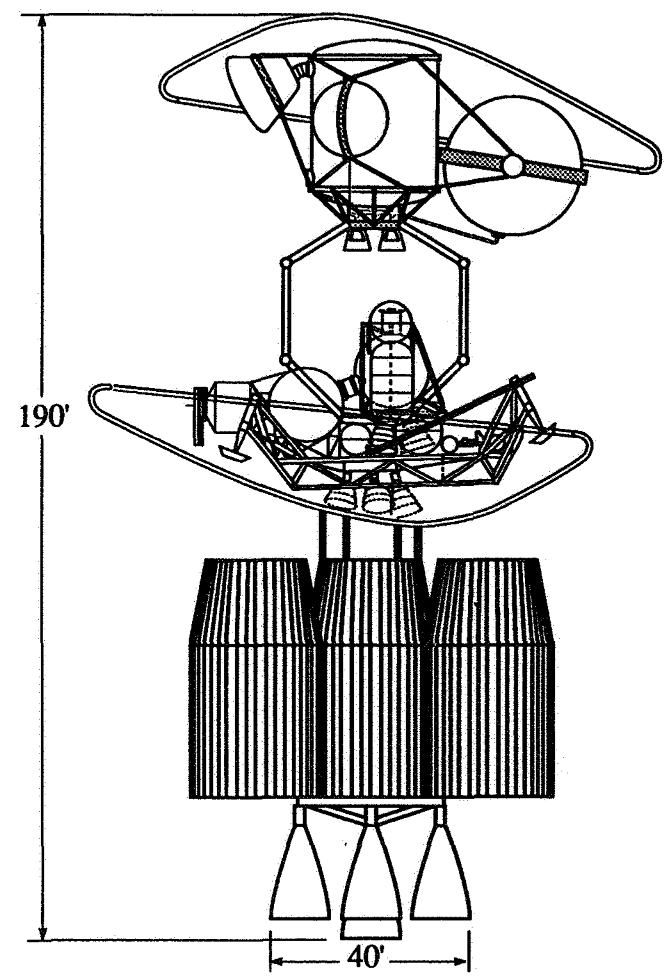
Launch Vehicle	Titan IV	Atlas II	Delta II
Payload to LEO	39-50K	15-20K	9-11K
Availability Date:	Jan 89	1991	Jan 89

New Cargo Element Requirements: Lunar and Mars Transportation Vehicles

Lunar Transfer and Excursion Vehicles



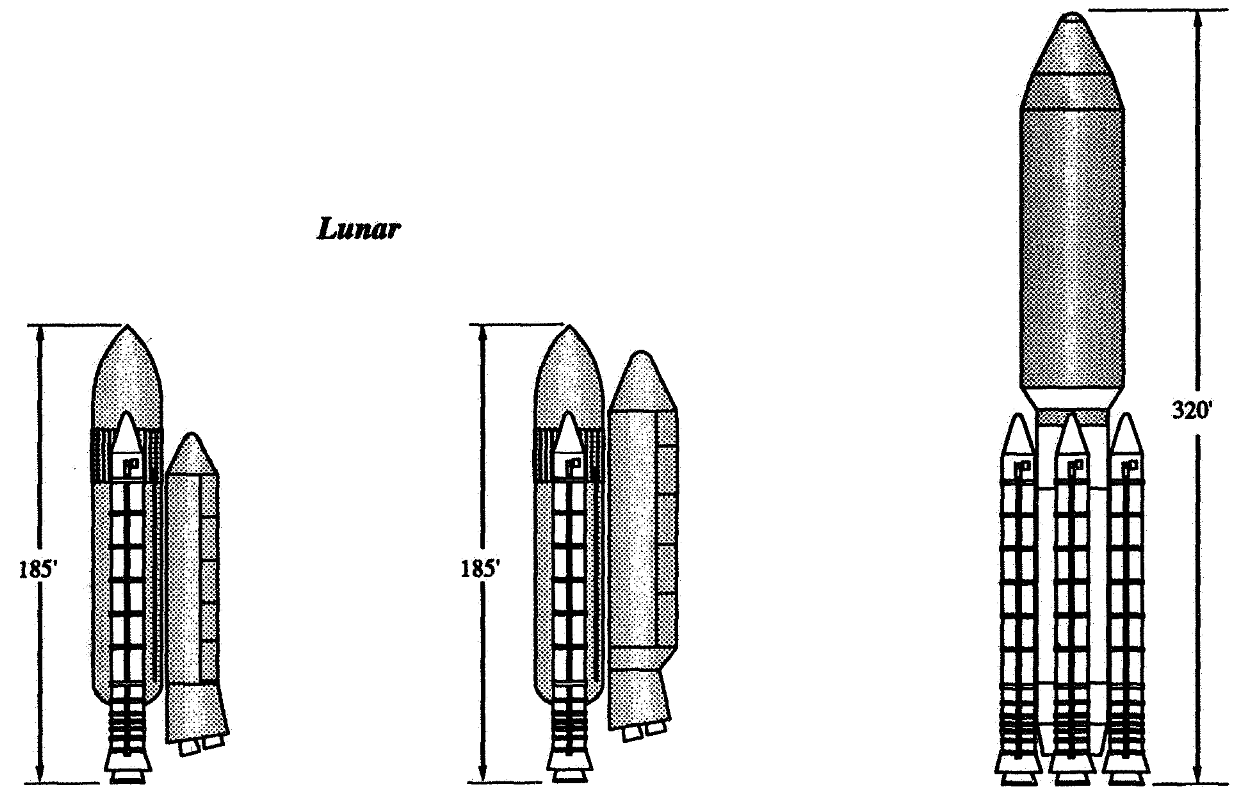
Mars Transfer and Excursion Vehicles



Shuttle Derived Vehicles for Lunar and Mars Missions Requirements

Advanced Avionics Technologies

Lunar | *Mars*



Lunar

Net Payload	157K
Boosters	2 ASRB's
Core Stage	Standard ET
Core Propulsion	3 SSME's
Payload Envelope	15' Dia. 82' Length

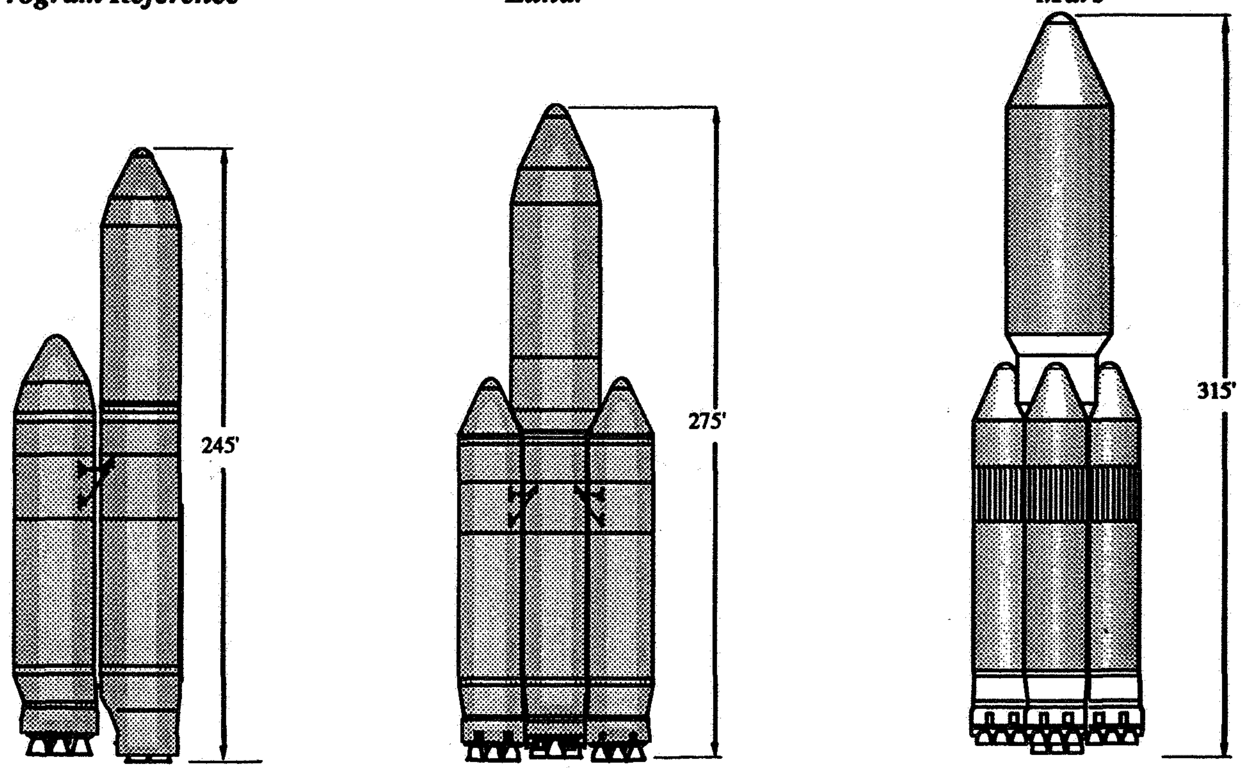
Net Payload	135K
Boosters	2 ASRB's
Core Stage	Standard ET
Core Propulsion	3 SSME's
Payload Envelope	25' Dia. 90' Length

Mars

Net Payload	300K
Boosters	4 ASRB's
Core Stage	New 30' Dia.
Core Propulsion	Recoverable P/A w/5 SSME's
Payload Envelope	40' Dia. 100' Length

Advanced Launch System (ALS) for Lunar and Mars Missions Requirements

Program Reference | *Lunar* | *Mars*



Program Reference

Net Payload	115K
Boosters	1 LOX/LH_2 w/6 STME's
Core Stage	LOX/LH_2
Core Propulsion	3 STME's
Payload Envelope	25' Dia. 100' Length

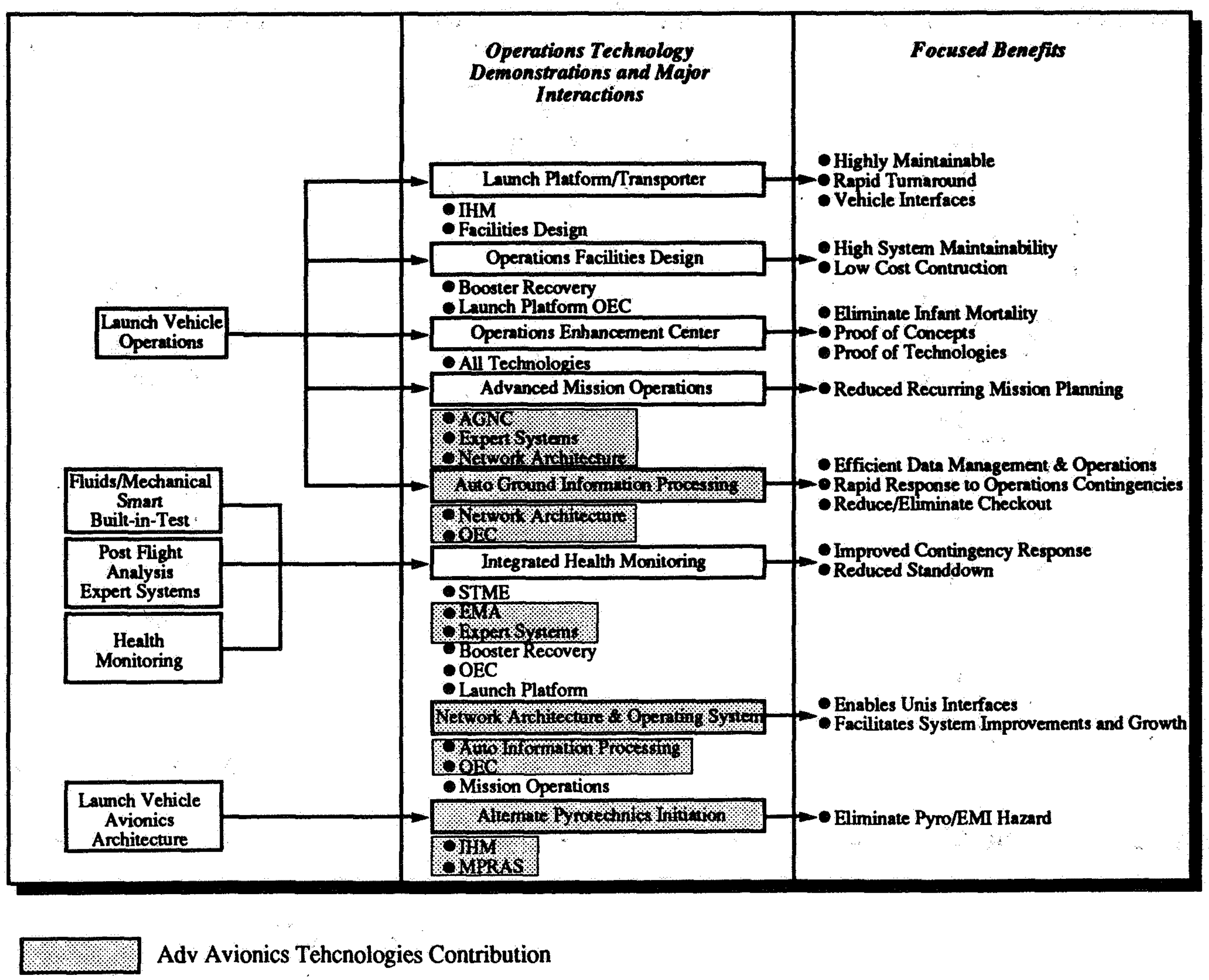
Lunar

Net Payload	215K
Boosters	2 LOX/LH_2 w/6 STME's ea.
Core Stage	LOX/LH_2
Core Propulsion	3 STME's
Payload Envelope	33' Dia. 100' Length

Mars

Net Payload	300K
Boosters	3 LOX/LH_2 w/6 STME's ea.
Core Stage	LOX/LH_2
Core Propulsion	3 STME's
Payload Envelope	40' Dia. 100' Length

Operations Benefit Through Advanced Avionics Implementation



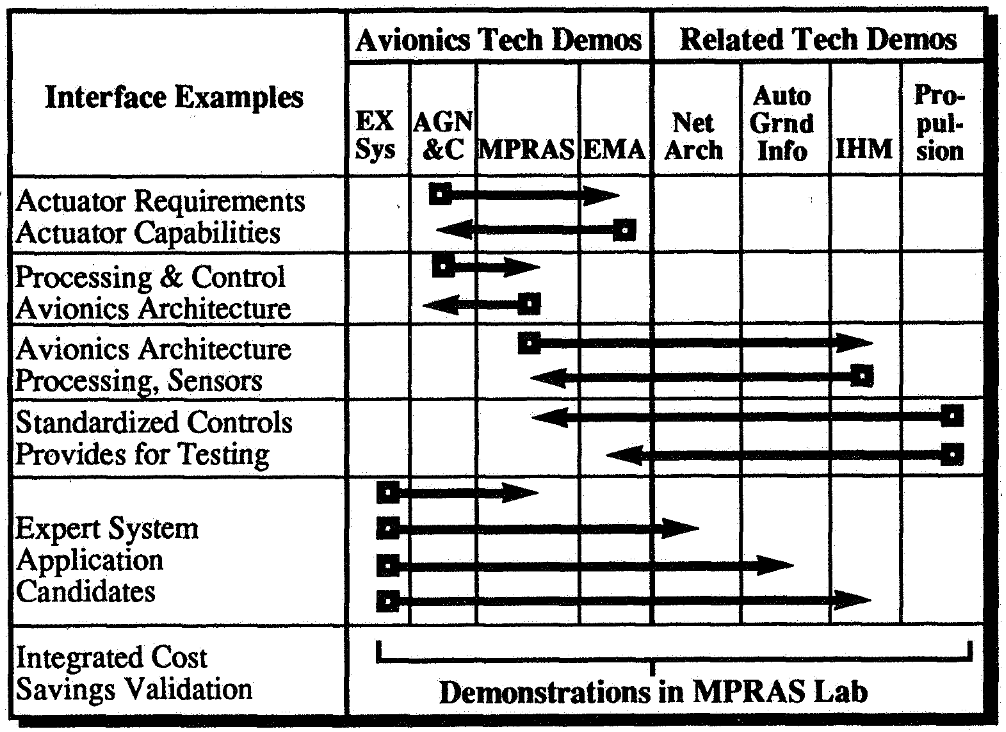
Technology Prioritization for Advanced Cargo Launch Vehicles

Advanced Avionics Technologies

Rank	Title	Contribution	Rationale
1	STME(E)-LO_2/LH_2 Gas Generator	Propulsion Cost	
2	STME(E)-LO_2/LH_2 Split Expander	Propulsion Cost	
3	STME(E) Vehicle/Engine Definition	Propulsion Cost	Major
4	Booster Recovery Module	Propulsion Cost (Booster Recovery & Eng Reuse)	
5	Expendable Tanks & Structures	Core & Booster Structures Cost	Cost
6	MPRAS	Cost & Enables AGN&C and Vehicle Reliability	
7	Integrated Health Monitoring	Operations Cost, Engine & Vehicle Reliability	Impact
8	Composite Payload Shroud	Shroud Structures Cost	
9	Interchangeable Avionics	Backup Avionics Cost	
10	Ops Facitilies Design-Ind Prep	Schedule-Preparedness for Assembly & Launch	Schedule
11	Launch Platform/Transporter	Transporter Cost and Schedule	Impact
12	Mantech-Automated Welding & NDE	Manufacturing Cost of Structures	
13	Operations Enchancement Center	Validates Ops Cost & Procedures	Enables & Validates
14	Expert Systems	Enables AGN&C, Health Mon, & Automated Ops	Other Technologies
15	Mantech-Composite Structures	Manufacturing Cost of Structures	
16	Advanced Mission Operations	Mission Planning Costs	
17	AGN&C	Mission Planning Cost & Vehicle Robustness	
18	Network Architecture	Ops and Facilities (Computer) Cost & Schedule	Lesser
19	Solid Rocket Booster	Backup Propulsion Cost and SRB Reliability	
20	Electromech Act/Power Supply	Operations Checkout Cost	Cost
21	Auto Ground Info Processing	Information Processing Costs	
22	Core Deorbit	Cost and Technology Risk Reduction	Impacts
23	Aero Data Bases	Supports Structure Cost Reduction	
24	Alternate Pyrotechnics Initiation	Operations Cost	

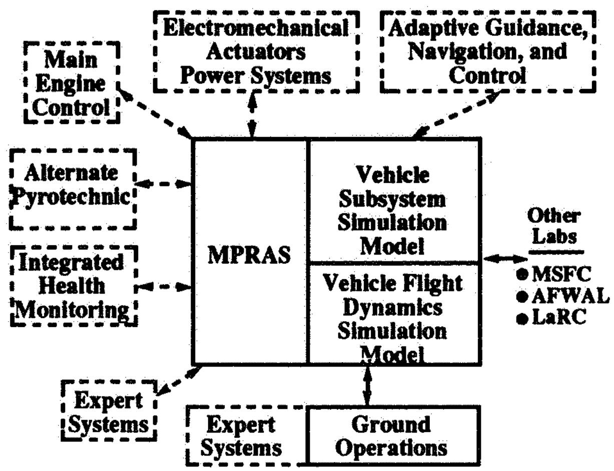
Avionics 33% of Top Priority Element

Avionics Technologies Interaction with Other Vehicle Technology Areas



Multi-Path Redundent Avionics Suite (MPRAS) Approach to Reduce Costs

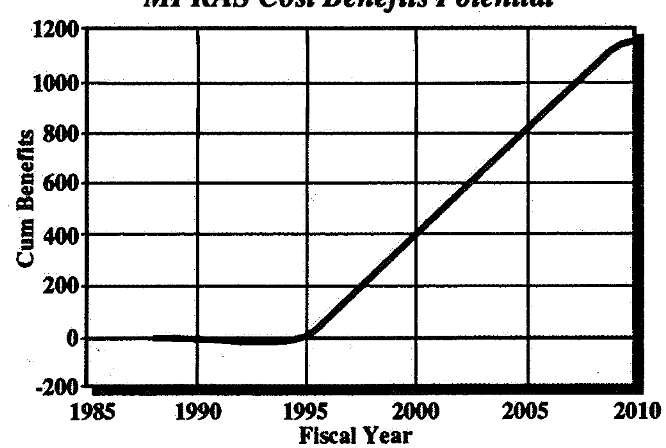
MPRAS: Integrated Avionics



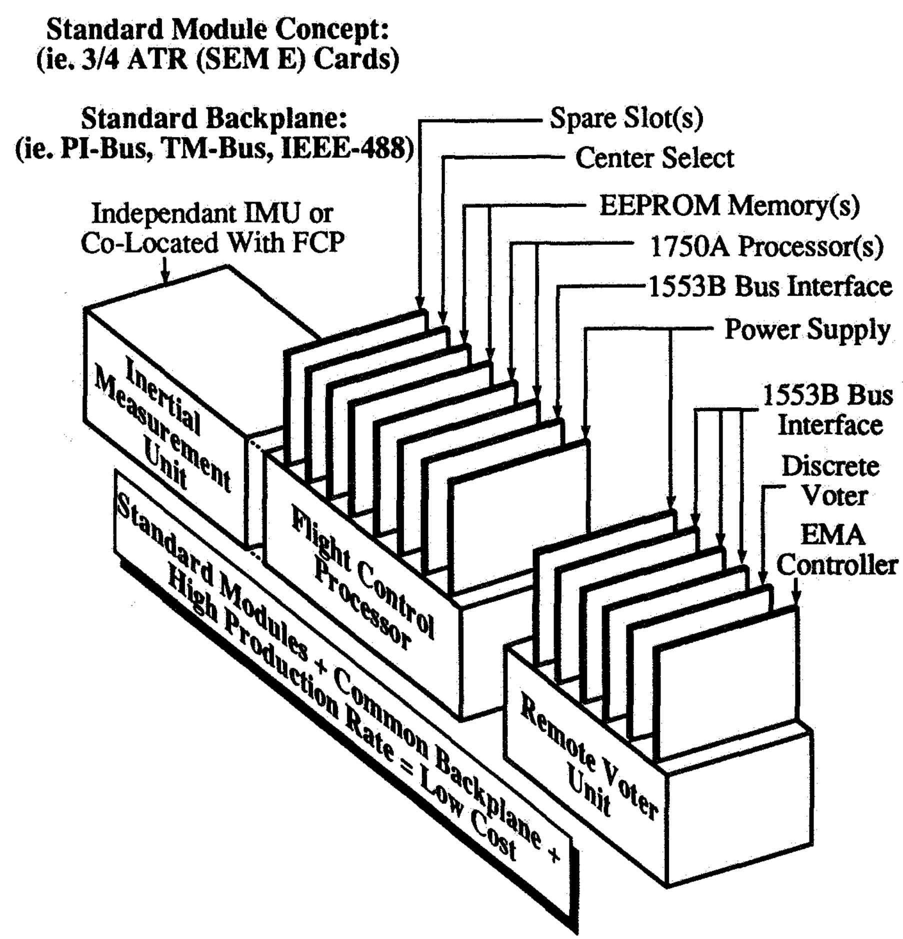
MPRAS Cost Savings Concepts

- Reduction of Hardware Cost
  - Common Modules
  - Standard Interfaces
  - Use of Data Buses
- Increased Reliability
  - Self-Test Modules
  - Redundancy
  - Reconfiguration
- Reduction of Operations Cost
  - Automatic Checkout
  - On-Board Data Processing
  - Mission Planning
  - Mission Analysis

MPRAS Cost Benefits Potential

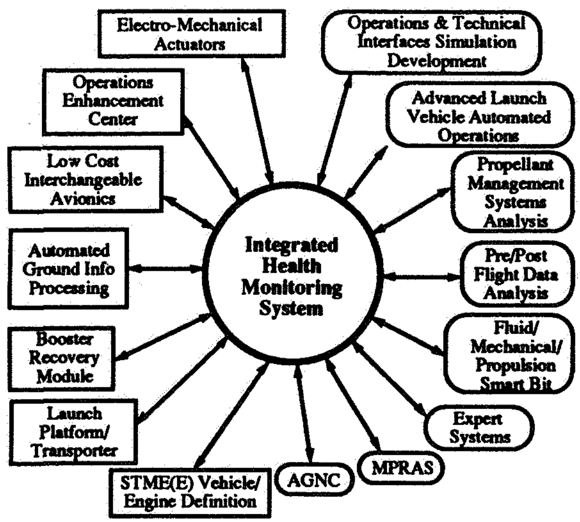


Interchangeable Avionics

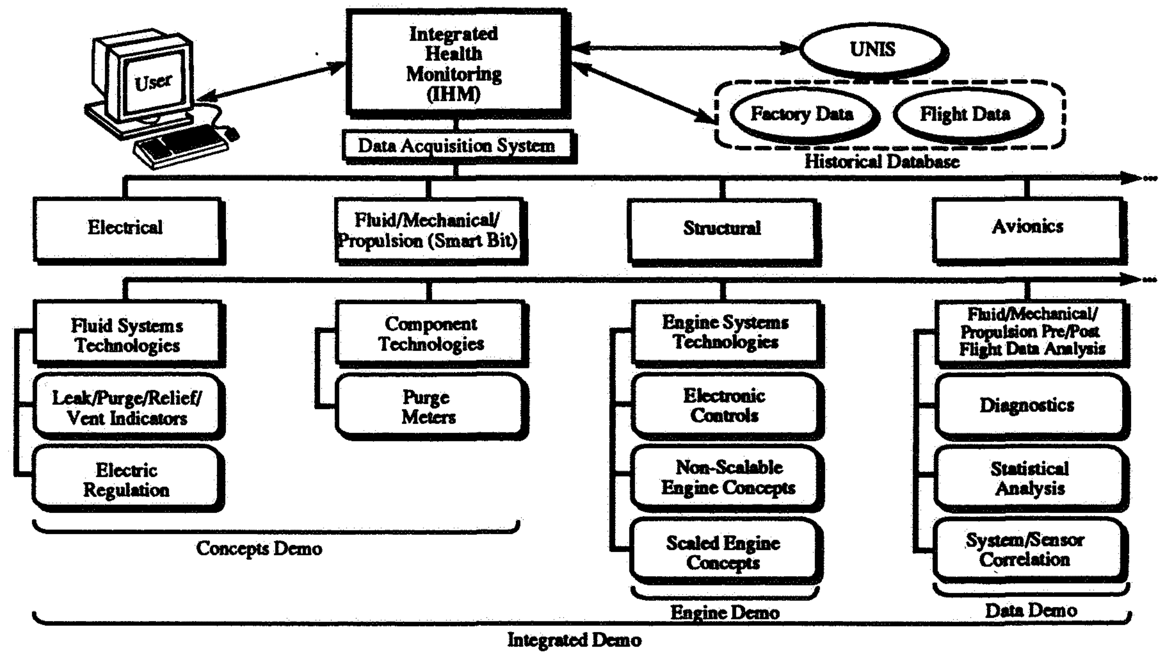


Integrated Health Monitoring (IHM)

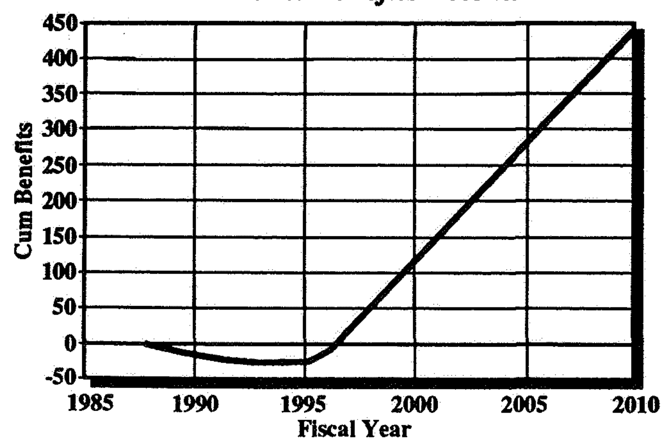
Representative Flow of Launch Vehicle Areas and IHM Concepts



IHM Technology Development

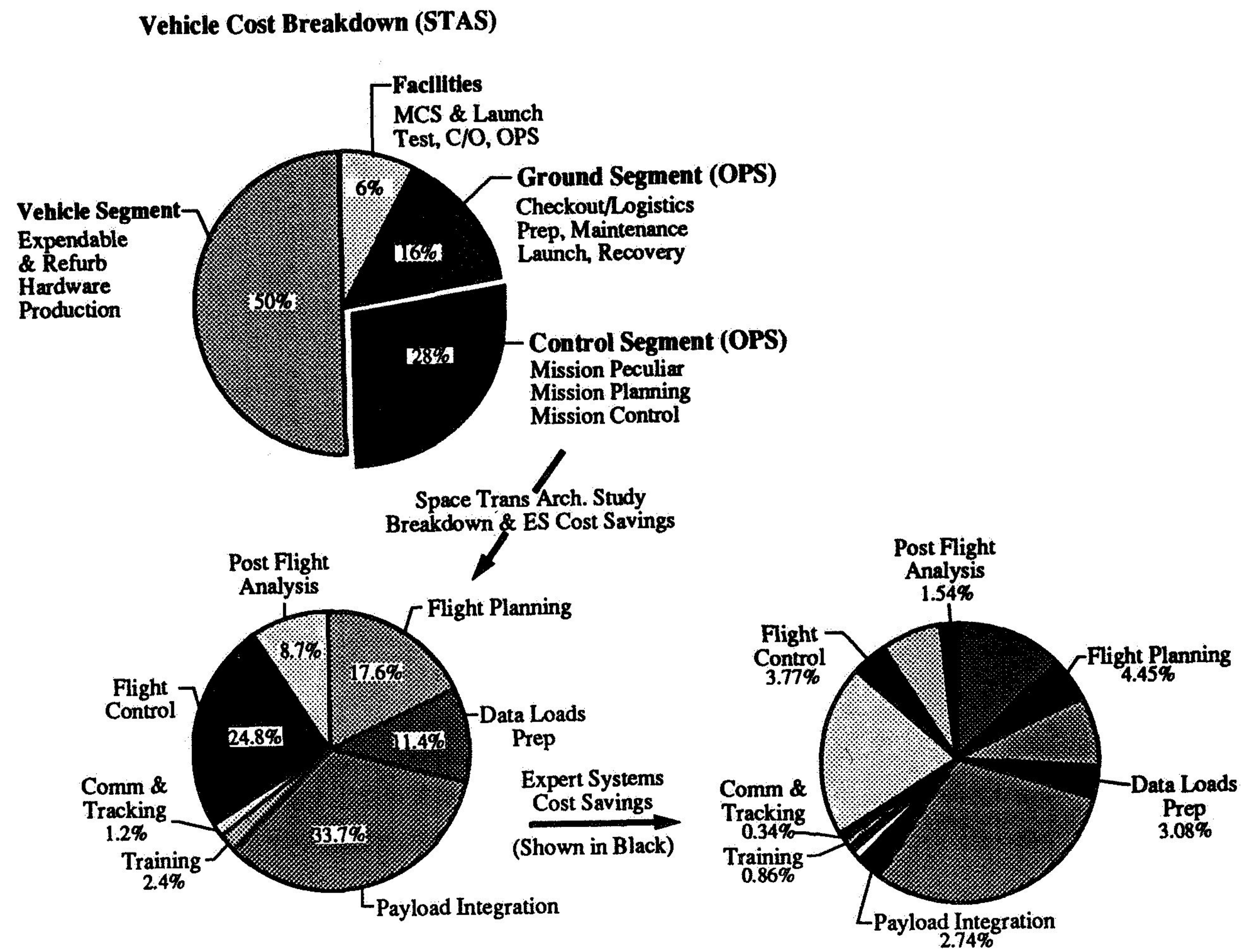


IHM Cost Benefits Potential



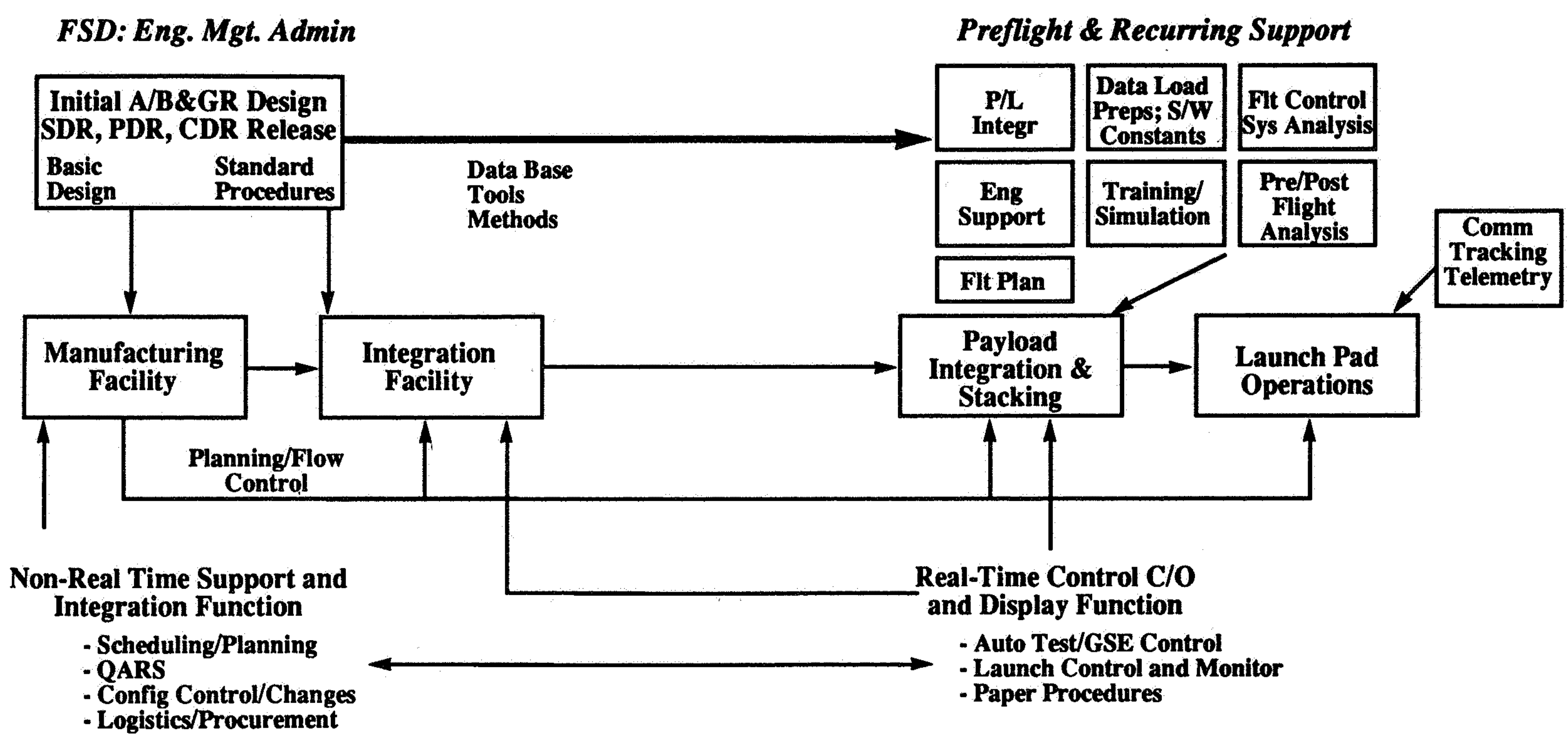
Expert Systems (Decision Support) Applications Contribution to Cost Benefits

Advanced Avionics Technologies

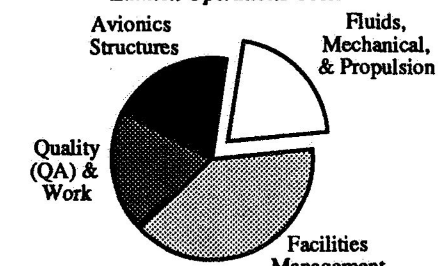


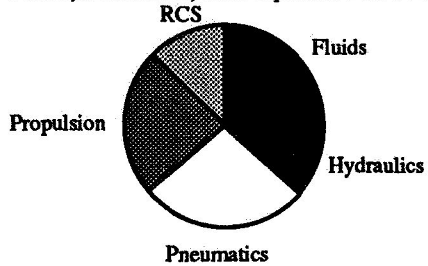
The Operations Function Flow Identifies Automation Opportunities

Advanced Avionics Technologies

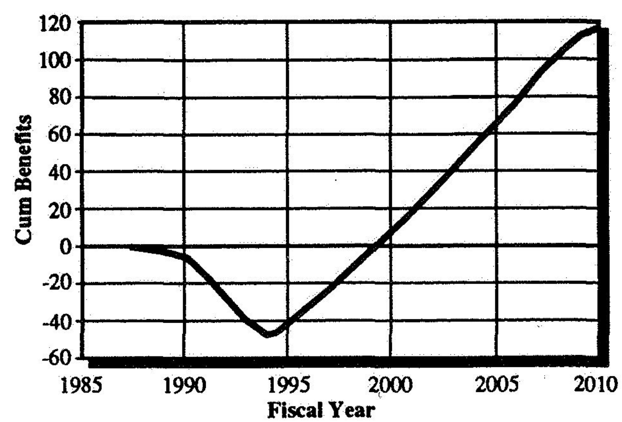


Potential Cost Savings From Electromechanical Systems





	HR	Savings Per Cent Used	Savings (HR)
Total ELV Launch Operations	91575		
Total F/M/P Test Time	19197		
Fluids	4928	10%	490
Hydraulics	2177	90%	1960
Pneumatics	5143	40%	2060
Propulsion	4616	20%	920
RCS	2333	<5%	0
			5430 HR
Equivalent Shuttle HRS			
Plumbing, Vent, and Drain	1069	20%	210
Hydraulics	1573	90%	1430
Propulsion	10099	40%	4040
ACS	2099	<5%	0
VAB Activities			5670
Pad Operations (35%)			3600
			9270 HR



EMA Cost Benefits Potential

Avionics Technology Transfer

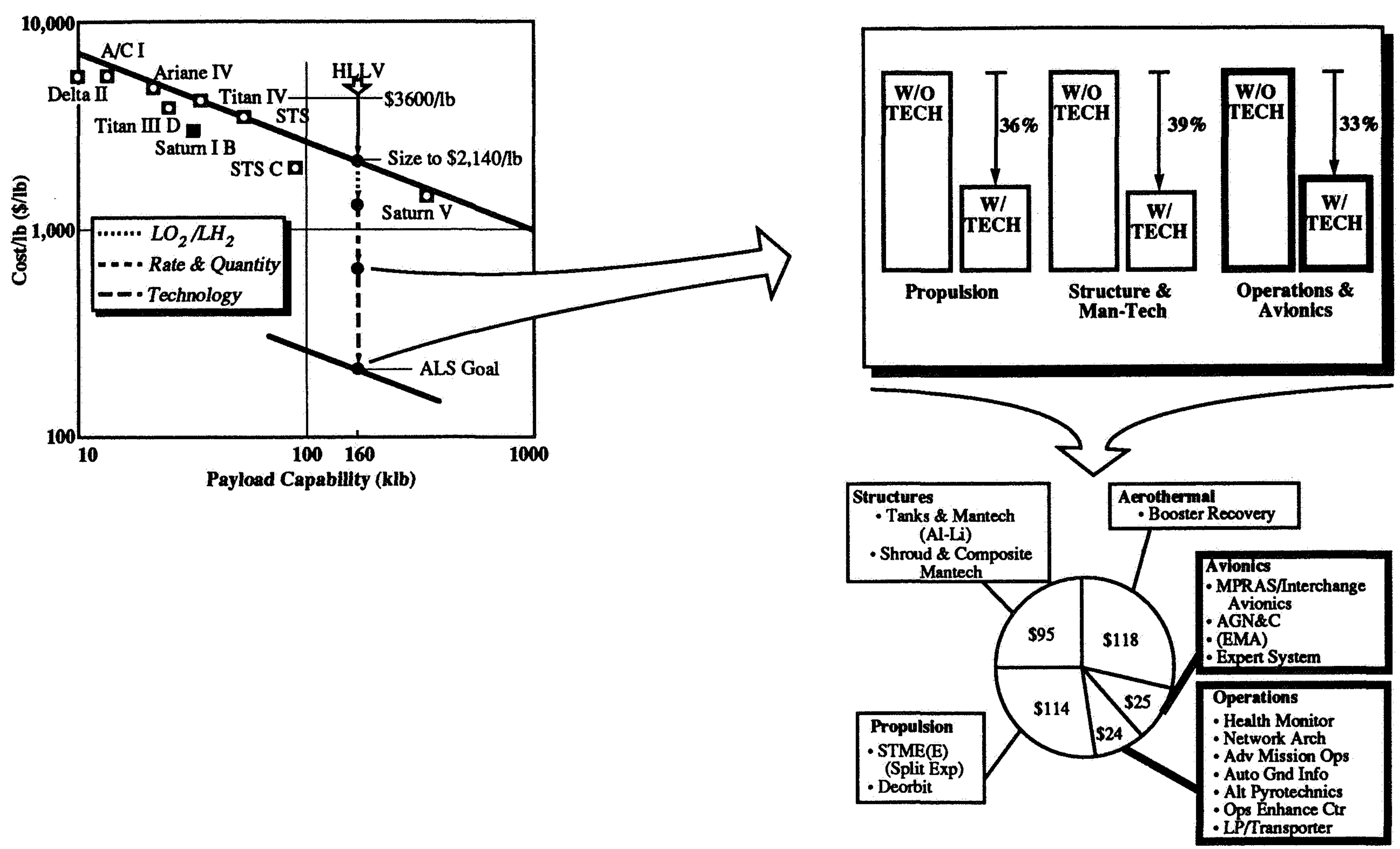
- **Expendable Launch Vehicles (ELV)**
  - Full System Demonstration In Valid Environments Permit Transfer Via:
    - -- Company Sponsored Efforts To Enhance System Competitiveness
    - -- Government Direction

- **Commercial Launch Vehicle**
  - <u>Do Not Develop New Technologies</u>
    - -- Incorporate Only After Full System Demonstration AND After Flight Vehicle Application
    - -- Must Benefit Hardware and/or Operations Cost

Avionics & Operations Technology Contributes Significantly to Lower Launch Costs

Target Cost Savings for Technology Developments

Projected Cost Savings for each Technology Development Area



SPACE STATION FREEDOM AVIONICS

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SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM

WILLIAMSBURG, VIRGINIA
NOVEMBER 7-9, 1989

SPACE STATION FREEDOM AVIONICS TECHNOLOGY

WHITE PAPER

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Office of Space Station
National Aeronautics and Space Administration
Washington, DC

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November 7-9, 1989

PROGRAM DESCRIPTION

The SSFP encompasses the design, development, test, evaluation, verification, launch, assembly, operation and utilization of a set of spacecraft in low Earth orbit (LEO) and their supporting facilities. The spacecraft set includes, as shown in Figure 1, the Space Station Manned Base (SSMB) and a European Space Agency (ESA) provided Man-Tended Free Flyer (MTFF) at an inclination of 28.5 degrees and nominal attitude of 410 km, a USA provided Polar Orbiting Platform (POP) and an ESA provided POP in sun-synchronous, near polar orbits at a nominal altitude of 822 km. The SSMB will be assembled using the National Space Transportation System (NSTS). The POP's and the MTFF will be launched by Expendable Launch Vehicles (ELV's): a Titan IV for the US POP and an Ariane for the ESA POP and MTFF.

The U.S. POP will for the most part use derivatives of systems flown on unmanned LEO spacecraft. This paper concentrates on the SSMB portion of the overall program.

The SSMB or "Station" as referred to from here on will have the capability to be permanently manned with a crew of eight, and to have a nominal lifetime of at least 30 years. The advances over previous stations can be appreciated in Figure 2, which contrasts it to scale with Skylab and MIR. Figure 3 shows the principal Station elements and identifies the NASA Centers and international partners responsible for

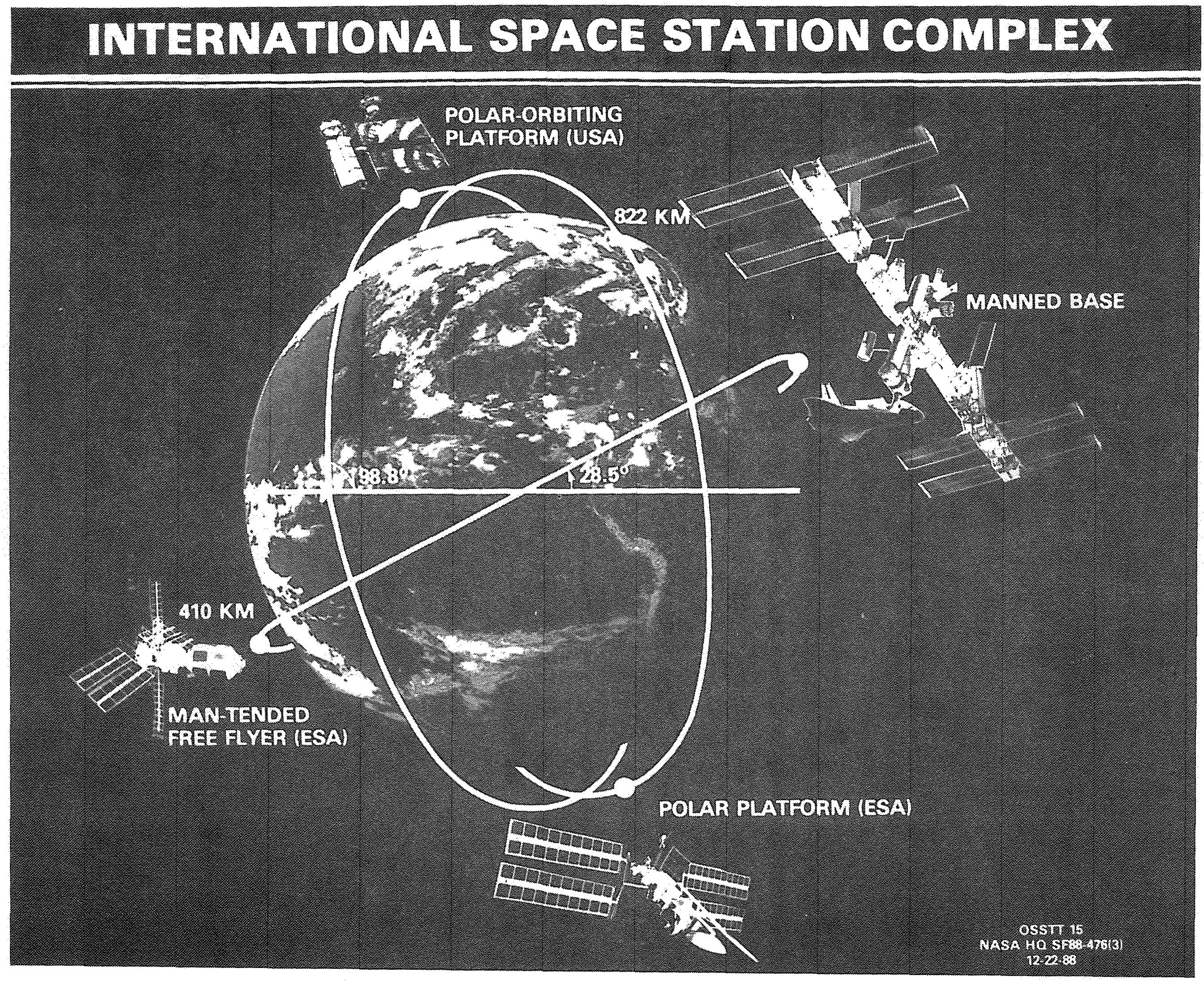
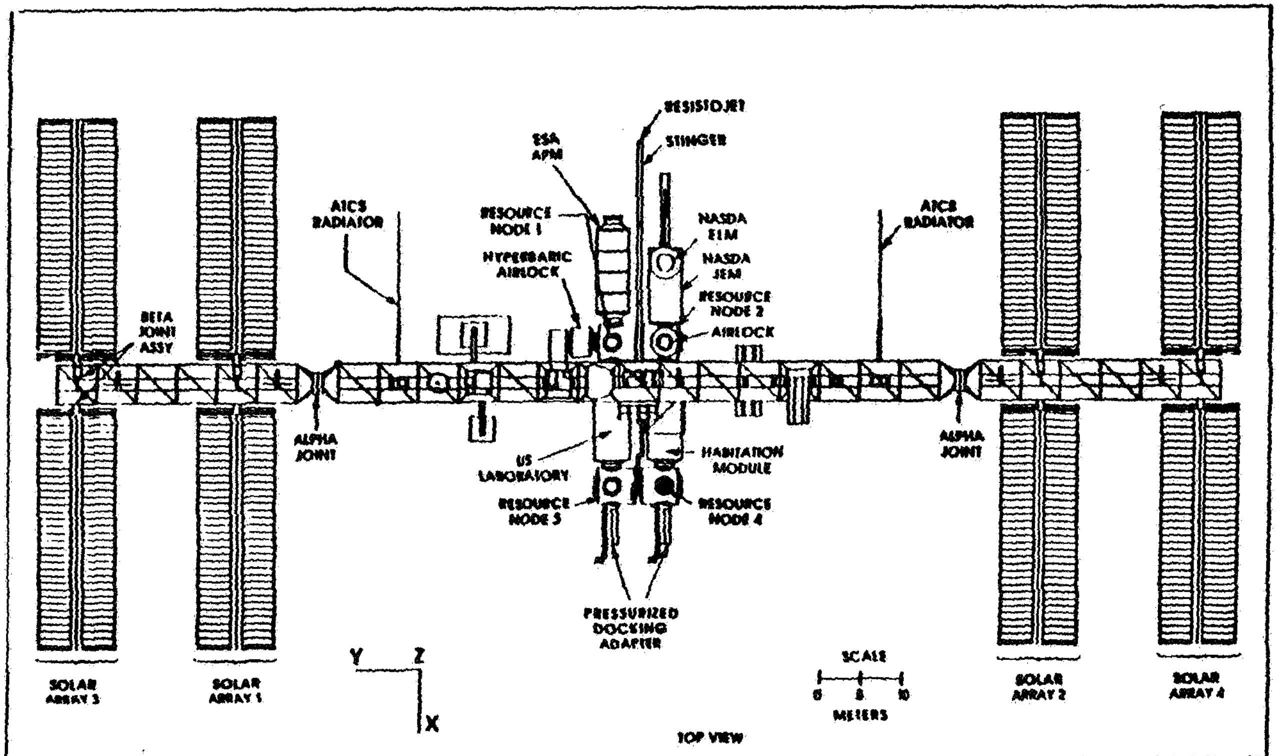
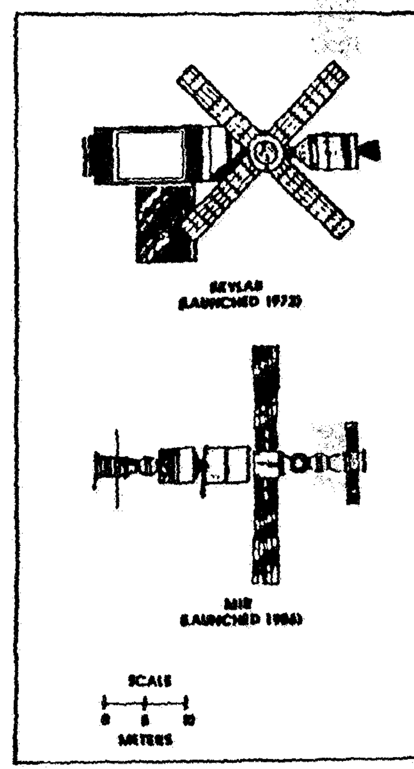

INTERNATIONAL SPACE STATION COMPLEX
POLAR-ORBITING
PLATFORM (USA)
822 KM
MANNED BASE
98.8°
28.5°
410 KM
MAN-TENDED
FREE FLYER (ESA)
POLAR PLATFORM (ESA)
OSSTT 15
NASA HQ SF88-476(3)
12-22-88

FIGURE 2
SPACE STATION FREEDOM MANNED BASE





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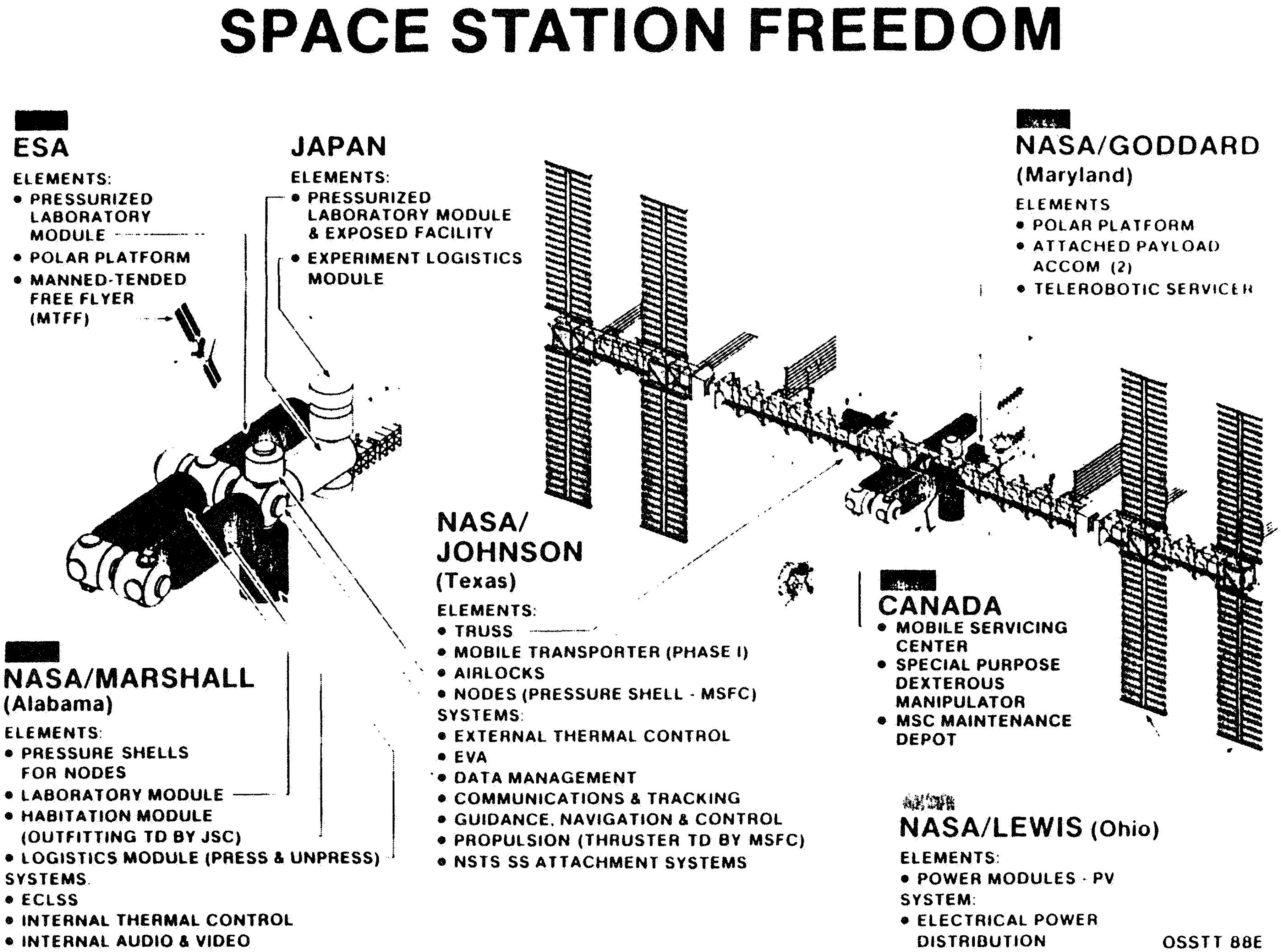

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these elements. The configuration has evolved from extensive analyses of scientific and commercial user requirements as well as transportation considerations, and engineering and technology factors. The program proposed as a result of the recent configuration budget review does not make major changes in the avionics complement at the completion of the assembly sequence, with the exception of a change from AC to DC primary power distribution.

Station elements will be attached to an 80 meter transverse boom oriented perpendicular to the velocity vector. Four pressurized cylindrical modules will be located in the center of the Station. The Habitation module will provide living quarters, and the United States, ESA, and Japan will each develop a laboratory module. The Japanese module also has an exposed facility. Also, pressurized and unpressurized logistics carriers will provide supplies and equipment.

There will be four resource nodes, located at each end of the Habitation and U.S. Laboratory modules. The nodes will be smaller pressurized cylinders that will generally serve as command and control centers, and as pressurized passageways to and from the various modules. The nodes may also accommodate some experiment racks and will provide additional pressurized space.

Certain nodes will also contain berthing mechanisms for temporary attachment of either the Space Shuttle or the logistics modules. They will also have attaching elements to connect the node to the truss and modules. Two cupolas will be attached to node ports to allow direct viewing of external activities. The nodes will also contain docking equipment and hatches. There will be a single hyperbaric airlock to support extravehicular activities (EVA).

The Station will be powered by two power modules, each composed of two pairs of photovoltaic arrays. The T-shaped power modules will be attached to either end of the transverse boom with two alpha joints, which will rotate to point the solar arrays

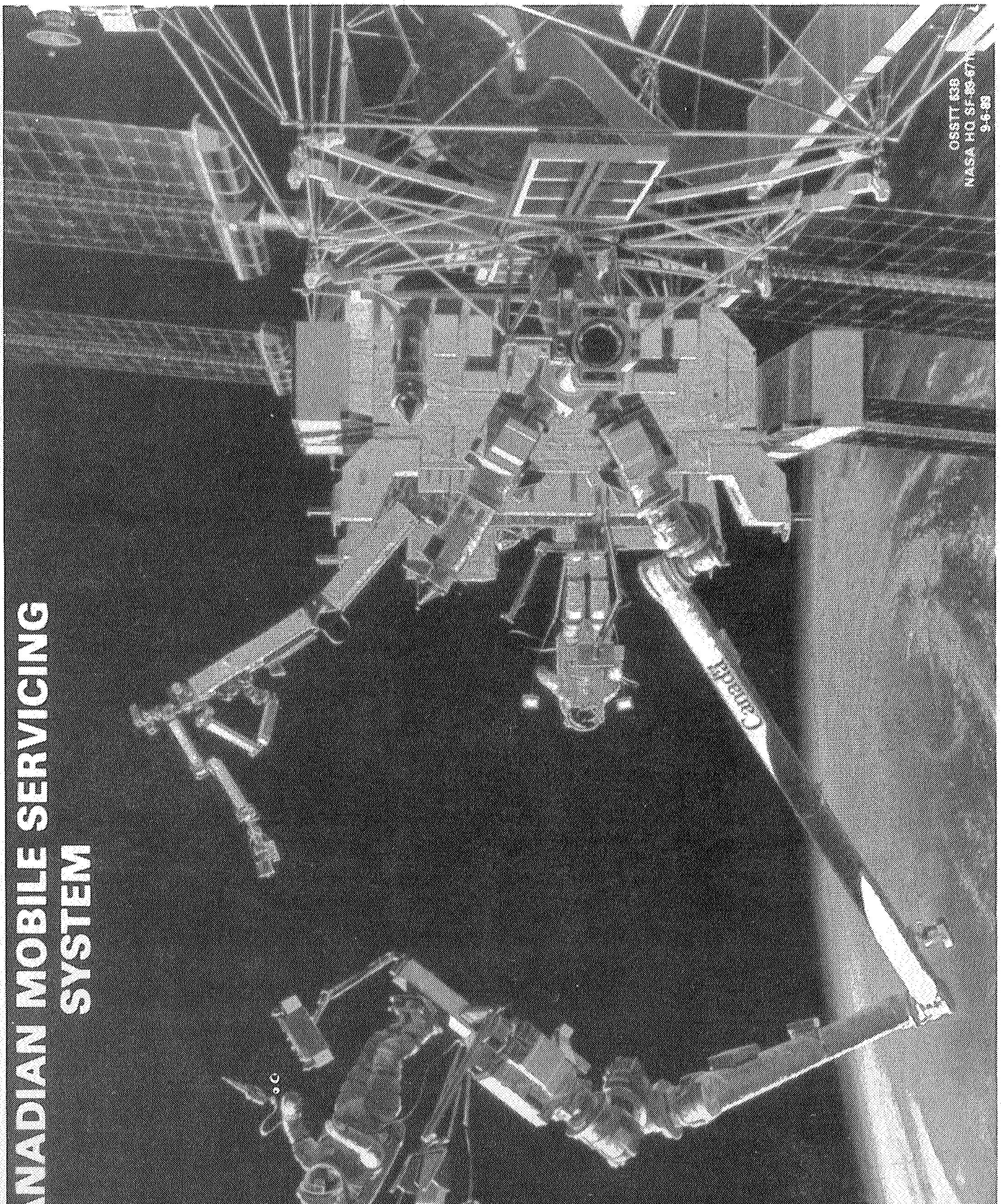
toward the sun. The power modules will supply an average total of 75 kilowatts (kW) of electrical power. The boom will be equipped with attach points providing power and other utilities to accommodate external scientific payloads.

Other features of the Station will include a Canadian Mobile Servicing System, shown in Figure 4. This system will be used to assist in the assembly of the Station and for a number of servicing tasks. There will also be a Flight Telerobotic Servicer (FTS), shown in Figure 5, which will be used for maintenance and which will also be used in the assembly of the Station.

The elements are the major pieces of hardware that are assembled to make up the Station, and comprise the hardware that is not involved with distributing a utility or service. Distributed systems, in contrast, provide those functions whose end-to-end performance is located in two or more elements. The Station will have a number of distributed subsystems which will provide data management, thermal control, communications and tracking, guidance, navigation and control, environmental control, human life support and fluid management.

The Assembly Sequence perhaps is the most challenging aspect of the program. The Sequence has evolved and will continue to evolve through the preliminary design phase now in progress. Figure 6 is an example of a Sequence requiring 20 NSTS missions to reach assembly complete. A current estimate lists 29 missions including logistics flights. Each increment in the Sequence must meet NSTS payload weight, volume, and CG constraints, obey limits on EVA assembly time, and result in a viable spacecraft ready for the next increment. The avionics systems will be challenged to meet the requirements of many different configurations on-orbit.

The current schedule for development of the Station is shown in Figure 7. The next key event is the Preliminary Design Review (PDR) and preparations for that are in progress throughout the program, with reviews at the subsystem level beginning this



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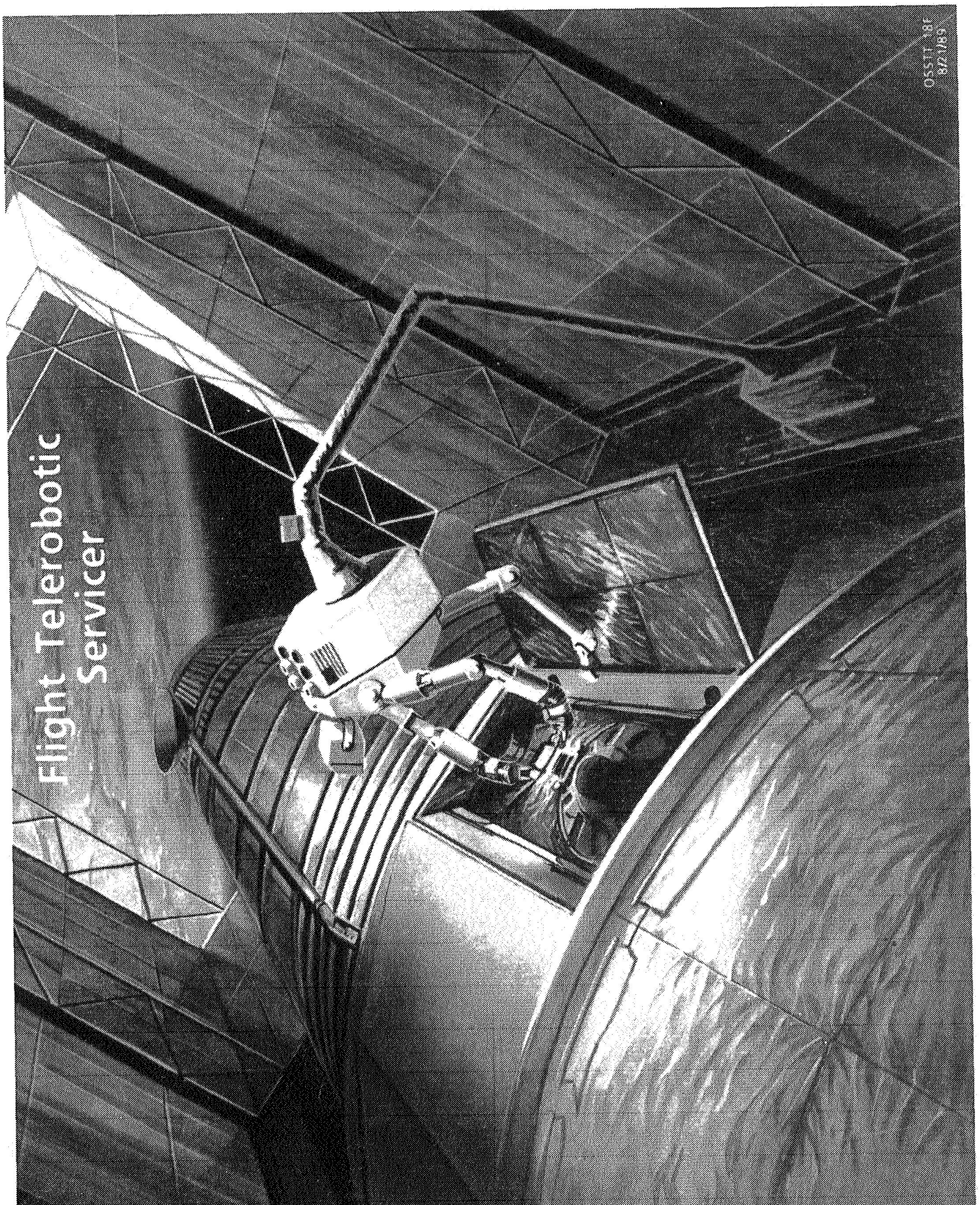
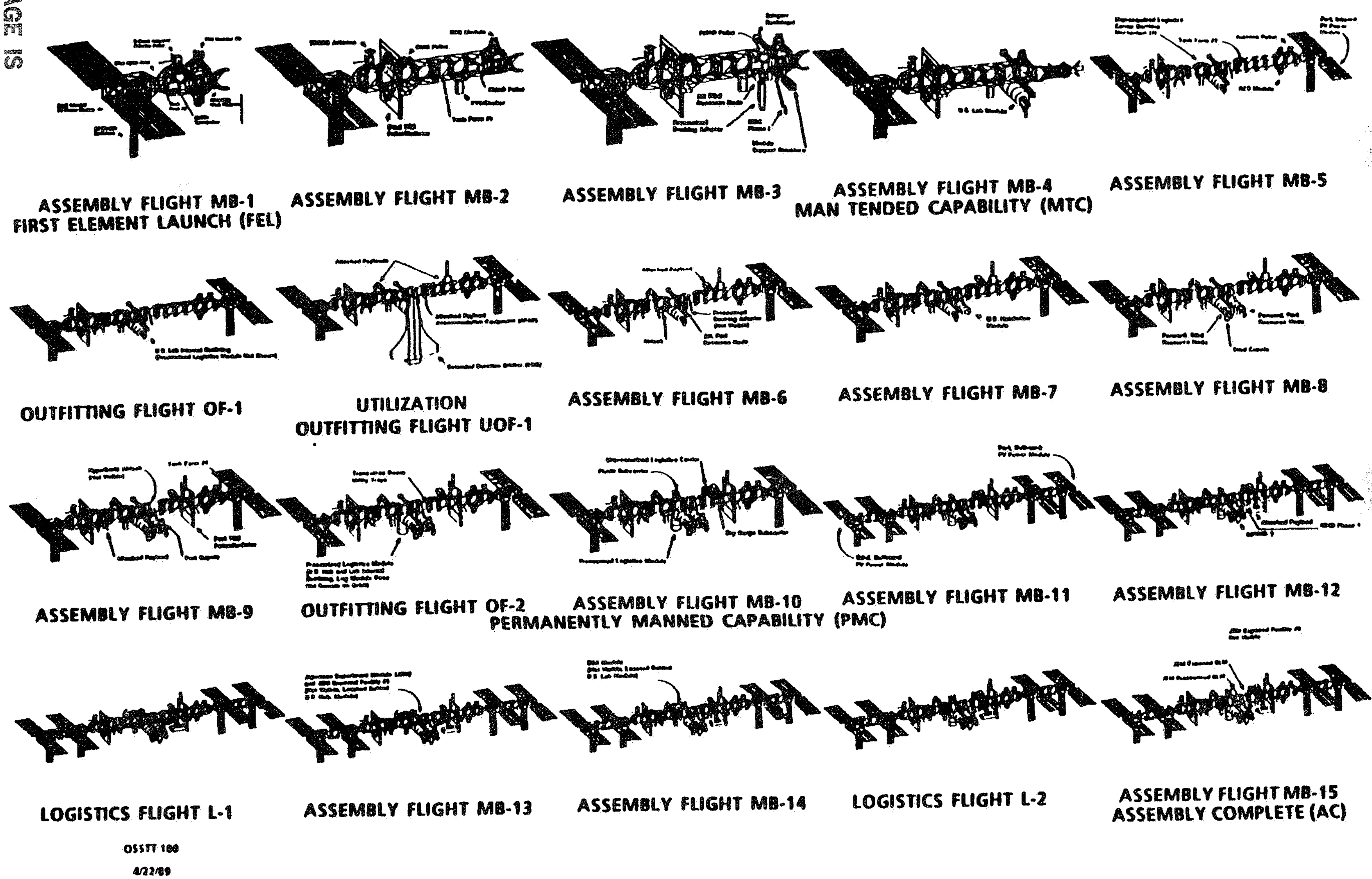

Flight Telerobotic
Servicer
OSST 18F
8/21/89

FIGURE 6
EXAMPLE OF
SPACE STATION FREEDOM ASSEMBLY FLIGHT SEQUENCE



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FREEDOM

FIGURE 7

SPACE STATION FREEDOM PROGRAM

PROGRAM SCHEDULE

MANNED BASE	BASELINE	PROPOSED
Phase C/D Start Date	Dec 1987	
Preliminary Requirements Review	Jun 1988	
Preliminary Design Review	Aug 1990	
Critical Design Review	May 1992	
Training Facility ORD*	Mar 1993	
Control Center ORD*	Mar 1994	
Processing Facility ORD*	Sep 1994	
Flight Readiness Review	Jan 1995	
First Element Launch	Mar 1995	
Man Tended Capability	Nov 1995	Apr 96
Permanent Manned Capability	Dec 1996	Jul 97
Assembly Complete	Feb 1998	Aug 99
FLIGHT TELEROBOTIC SERVICER		
Phase C/D Start Date	Jul 1989	
Preliminary Design Review	Jan 1990	Dec 90
Critical Design Review	May 1991	Jun 92
Development Test Flight	Dec 1991	Aug 91
Demonstration Test Flight	Jun 1993	Nov 93
Flight Unit Availability	Mar 1995	

* ORD = Operational Readiness Date

year. Phasing down of the DDT&E effort in the nineties should provide an opportunity to begin introducing evolutionary and growth development activity that could expand capabilities at the turn of the century. An example of an enhanced Station serving as a transportation node is shown in Figure 8. Featured are a dual keel providing more real estate, solar dynamic power modules to increase power, and accommodations for servicing. Other avenues of enhancement could support a Mars exploration initiative or increased research and development.

The principle avionic subsystems and related topics are discussed in the following sections with emphasis on the technical challenges and the anticipated paths for evolution.

ELECTRIC POWER SYSTEM (EPS)

The EPS provides a critical resource to the Station using PV modules as described earlier. The system includes NiH_2 batteries and power distribution hardware as shown in the top level architecture diagram of Figure 9. The baseline is now a totally DC system from the arrays through primary, secondary and tertiary distribution. Primary is at 160 V and secondary is at 120 V. There will be a development activity to obtain the necessary switch-gear to handle the 75 kW output power level. AC power for primary distribution was scrubbed in the recent program rephasing.

The estimates of power for housekeeping and power for users will continue to be refined as the design proceeds, but it is clear that the allocations will challenge experiment and system developers and the overall power management activity. Current estimates for housekeeping power are given in Figure 10 to indicate where improvements might bring significant benefits. DMS has the major requirement in avionics, but there is a challenge across the board is to improve efficiency and to enable an effective power management strategy.

LUNAR EVOLUTION REFERENCE CONFIGURATION
LEO Transportation Node

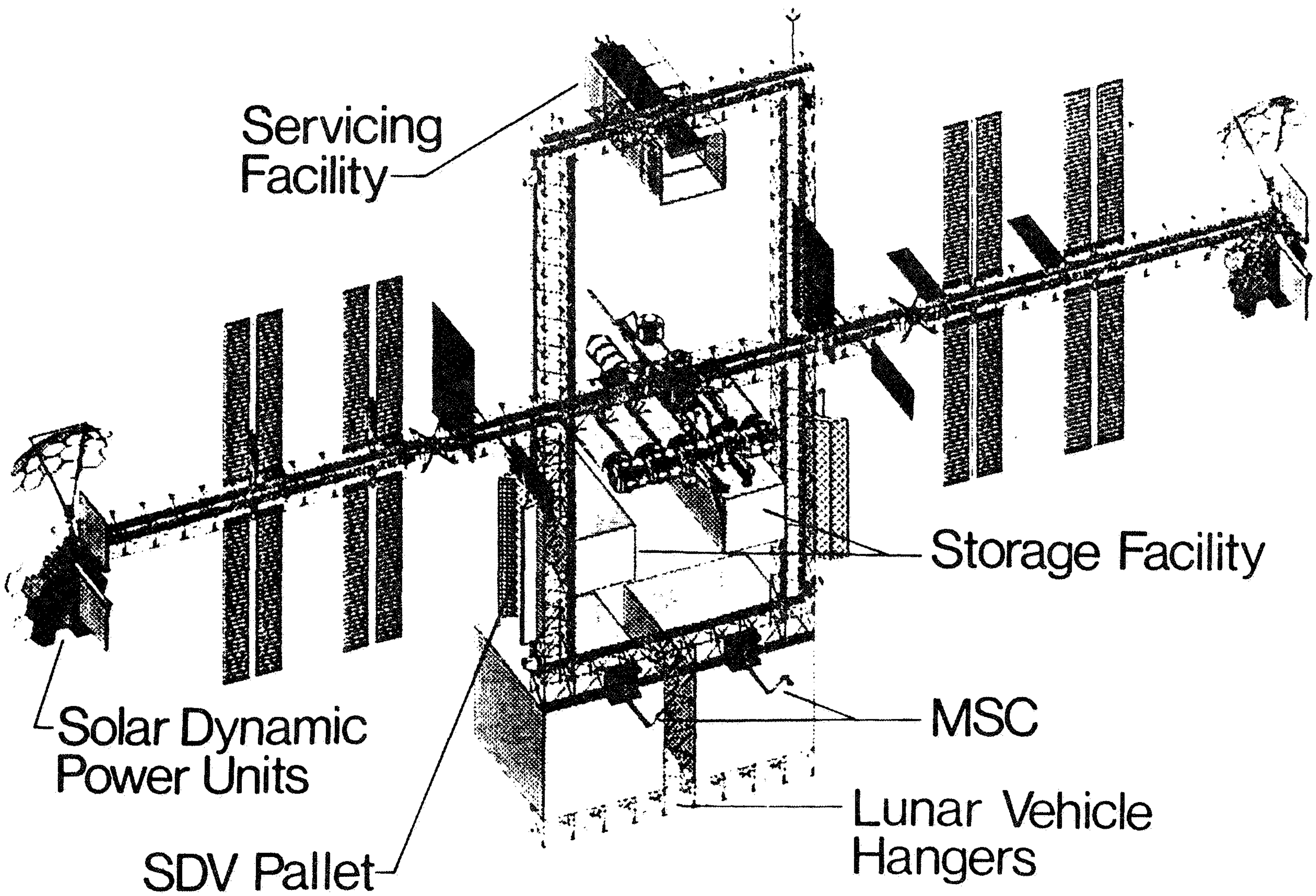

FIGURE 9
END-TO-END ARCHITECURE

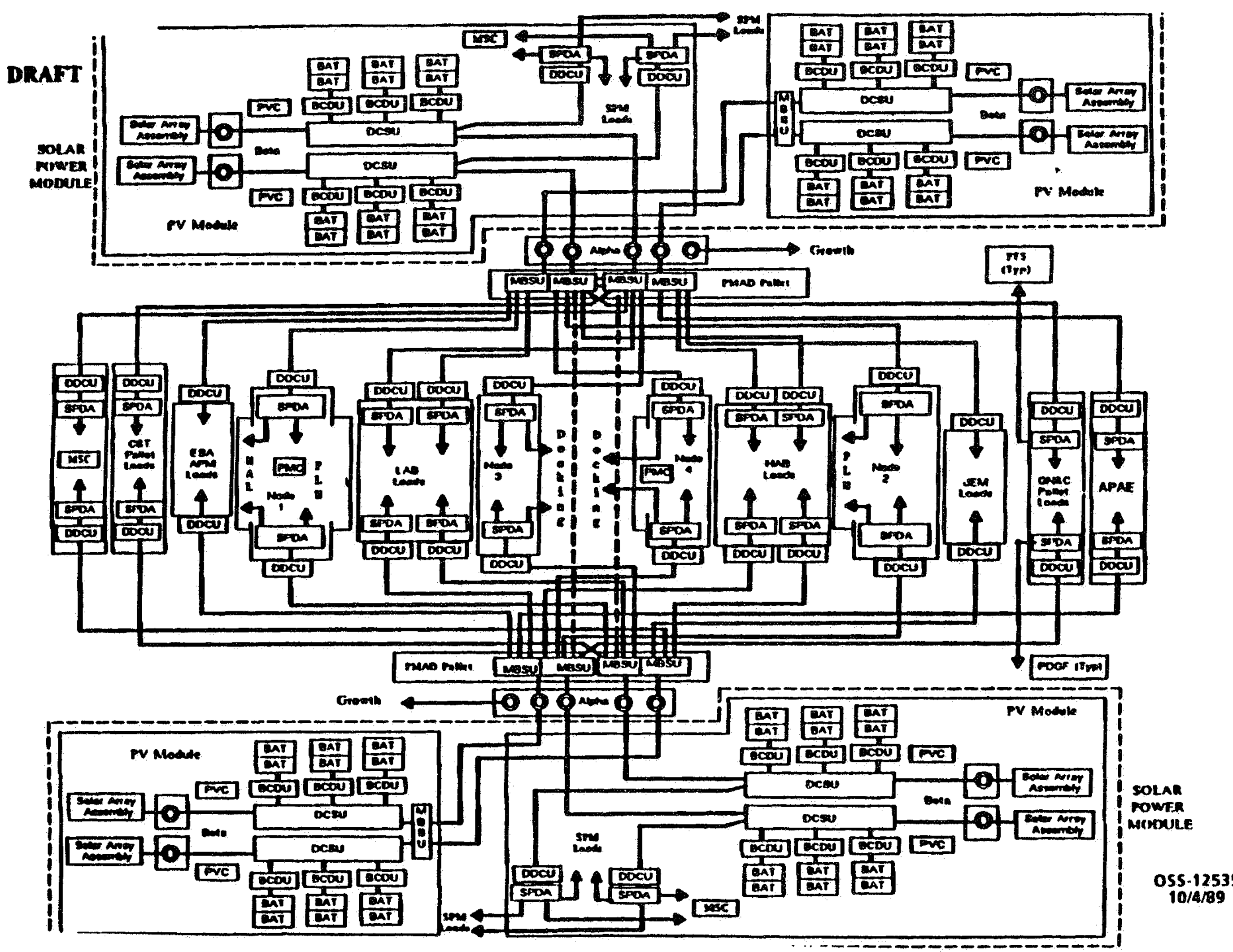

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FIGURE 10
HOUSEKEEPING POWER ESTIMATES

Distributed System	Assembly Complete* (kW•hr/hr)	
ECLSS	10.89	
Propulsion	1.35	
Internal Thermal	2.97	
External Thermal	0.61	
Fluids	1.35	
C&T	1.77	
Internal A/V	1.25	
GN&C	0.57	
DMS	4.94	
Man-Systems	4.30	
EVA	0.13	
Mechanisms	0.85	
Element Unique	4.48	
Distribution Losses	3.76	
CSA	2.76	
ESA	2.37	(5.02)**
NASDA	3.77	(1.89)**
TOTAL	48.12*	(55.03)**

Notes: No reserves included
* *Assumes U.S. Lab active and International Lab quiescent*
** *All labs active*

The growth path for the EPS would be to implement the Solar Dynamic Module shown in Figure 11 and to implement an AC primary distribution at 440 V and 20 kHz. The Solar Dynamic approach using a solar concentrator and Brayton cycle has higher efficiency than the PV and presents a smaller area with less drag than PV. In addition, the energy storage would employ a material phase change instead of batteries. The reduction in logistics resupply and the on-orbit changeout task relative to solar cells and batteries would be significant. The Solar Dynamic Modules would provide 25 kW increments and be symmetrically positioned outboard of the initial PV modules. Solar Dynamic requires accurate pointing and a basic PV capability should always be retained to recover from a degraded pointing condition.

DATA MANAGEMENT SYSTEM (DMS)

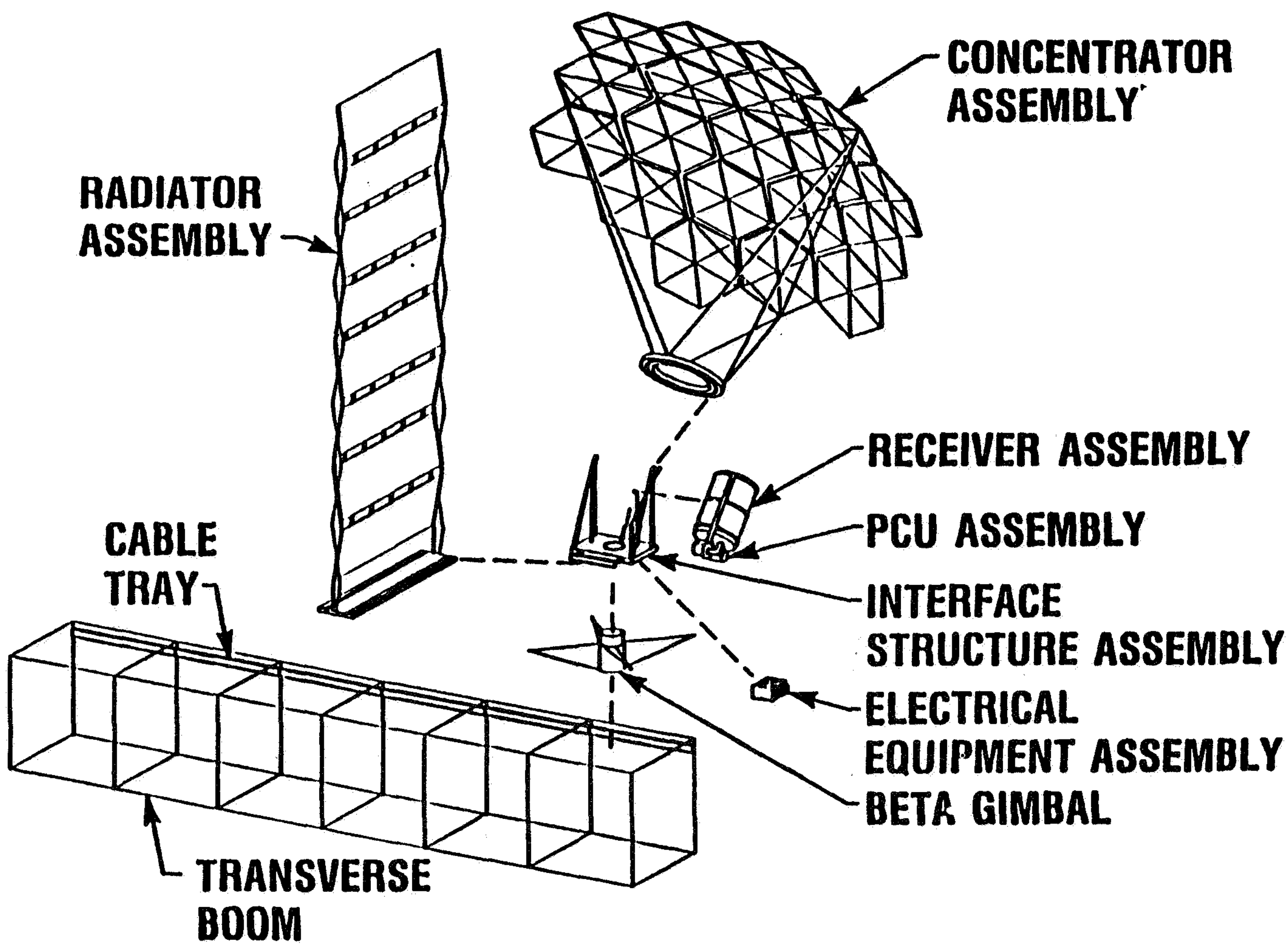
There has been general agreement that the DMS presents one of the top technical challenges in the Station program. The challenge arises from its size and complexity. The DMS will provide the hardware and software resources necessary to support the data processing and control needs of the other distributed systems, the elements and payloads. It will also provide a common operating environment and human-computer interface for the command and control of systems and payloads by both the crew and the ground operators.

The DMS will be made up of five subsystems corresponding to the five major DMS functions:

- Human-computer interface,
- Data acquisition and distribution,
- Data storage and retrieval,
- Application program processing, and
- Time generation and distribution.

FIGURE 11
SPACE STATION FREEDOM

SOLAR DYNAMIC POWER MODULE ASSEMBLIES



The major features of the DMS are given in Figure 12, and an overview schematic is given in Figure 13. Key features of the software development are the choice of ADA as the standard language and the definition of a Standard Software Environment (SSE) capability for commonality across the program. Some of the challenges facing the DMS development are:

- Ensuring common design guidelines are properly allocated to all software generated across the program.
- Establishing standard interfaces with international partners and the ground environment.
- Meeting power resource allocations.

COMMUNICATIONS AND TRACKING (C&T) SYSTEM

The C&T System, together with the DMS and associated ground systems, forms the Space Station Information System (SSIS). There is a major challenge in defining the overall end-to-end data system and controlling its configuration. The C&T System provides capability for sending audio, video, operational data and experiment data to the ground and for receiving command data from the ground using the Tracking and Data Relay Satellite System (TDRSS). A functional block diagram is shown in Figure 14.

The space to ground Ku Band link will use the full capability of TDRSS at 300 Mbps. The operational housekeeping data portion of this will be 2 Mbps. In addition, there will be an S-Band link to be used during early assembly flights and as a backup in the operational phase. An emergency link separate from TDRSS has been proposed that would carry only voice.

FREEDOM

FIGURE 12
MAJOR DMS FEATURES

REQUIREMENT	IMPLEMENTATION
Processing Architecture	- Distributed
On Board Data Distribution	- Combination of LAN's and Busses. (1553,802.4, FDDI) Payloads and Core Systems Separated
Controls and Display	- Multipurpose and Application Consoles, Fixed and Portable
Software	- ADA, Standard Interfaces, Common Services
Data Storage	- Replicated and Stand-Alone DMBS
Time Generation	- Independent Network, Use GPS for UTC Interface
Autonomous Operations	- OMS/OMA Command and Control Architecture
Integration, Test and Verification	- Common Test Environment
Software Development	- Common SSE
Processor	- INTEL 80386
LAN Data Rate	- 100 MBPS
Mass Storage	- Magnetic Disk
Standard Backplane	- Multibus II
Packaging	- MIL STD 1788

SELECTIONS YET TO BE MADE

Software, COTS vs. Custom	- Operating Systems, DBMS, DMS Services
Redundancy Management	- Levels, Techniques and Automation Factors
MPAC	- CRT's and Liquid Crystals, Network Interfacing
Time Services	- Time Code and Interfaces
DBMS Architecture	- Distributed or Centralized
End-to-End Network Protocols	- CCSDS, ISO/OSI
Security/Privacy	- TBD (Object Classification, Encryption of Data)

FIGURE 13
DMS OVERVIEW SCHEMATIC

FREEDOM

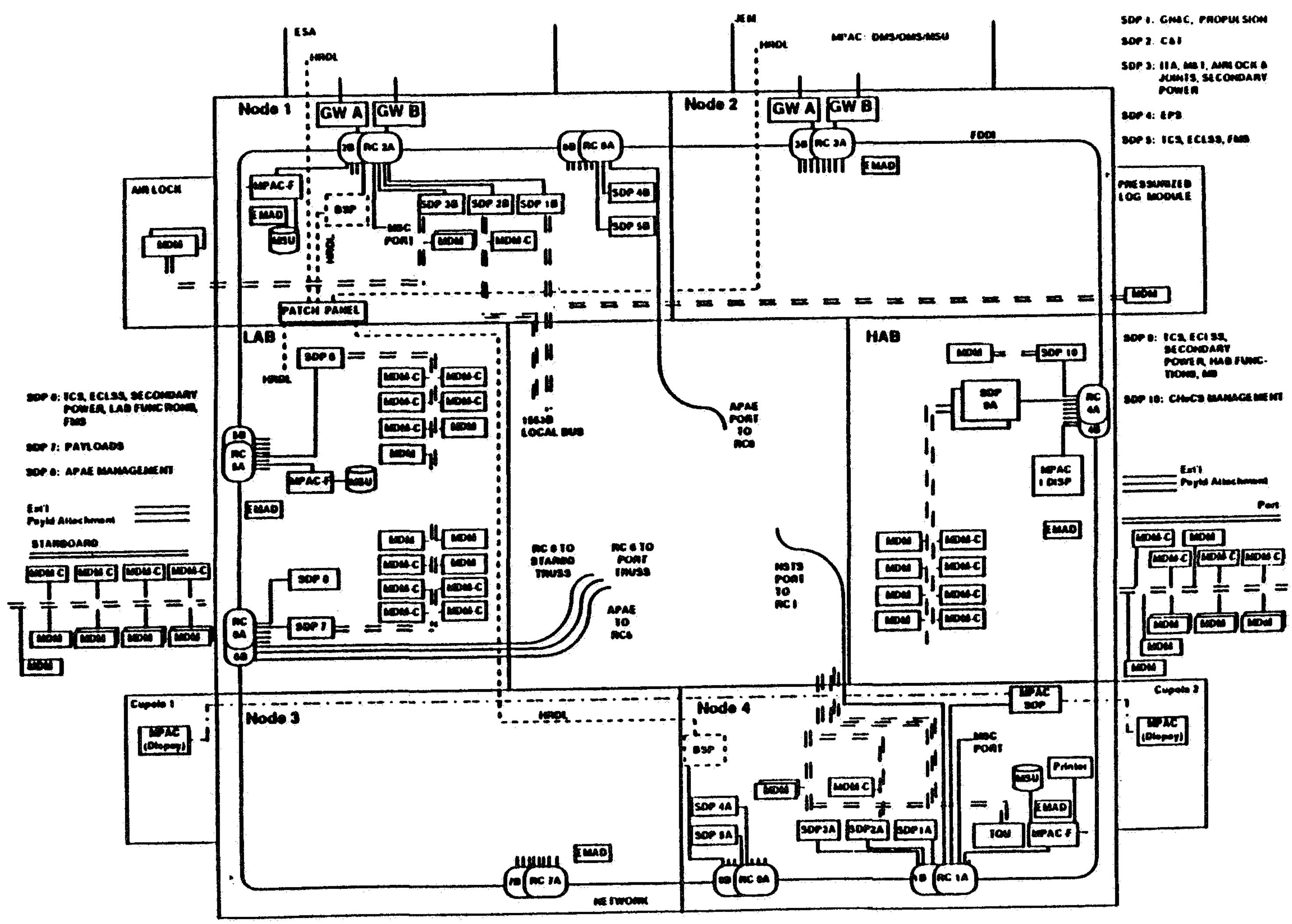


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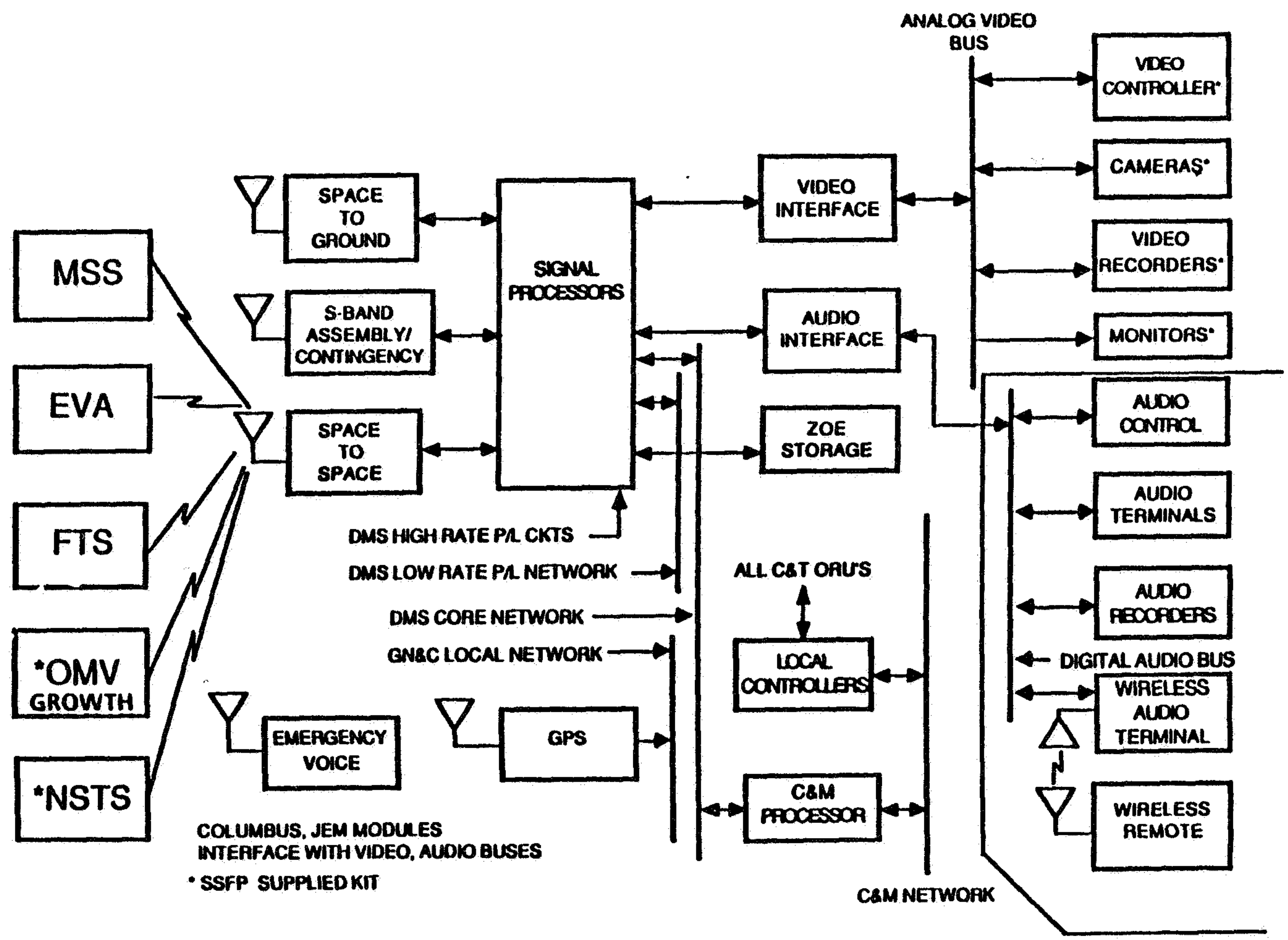
FIGURE 14
C&T FUNCTIONAL BLOCK DAGRAM



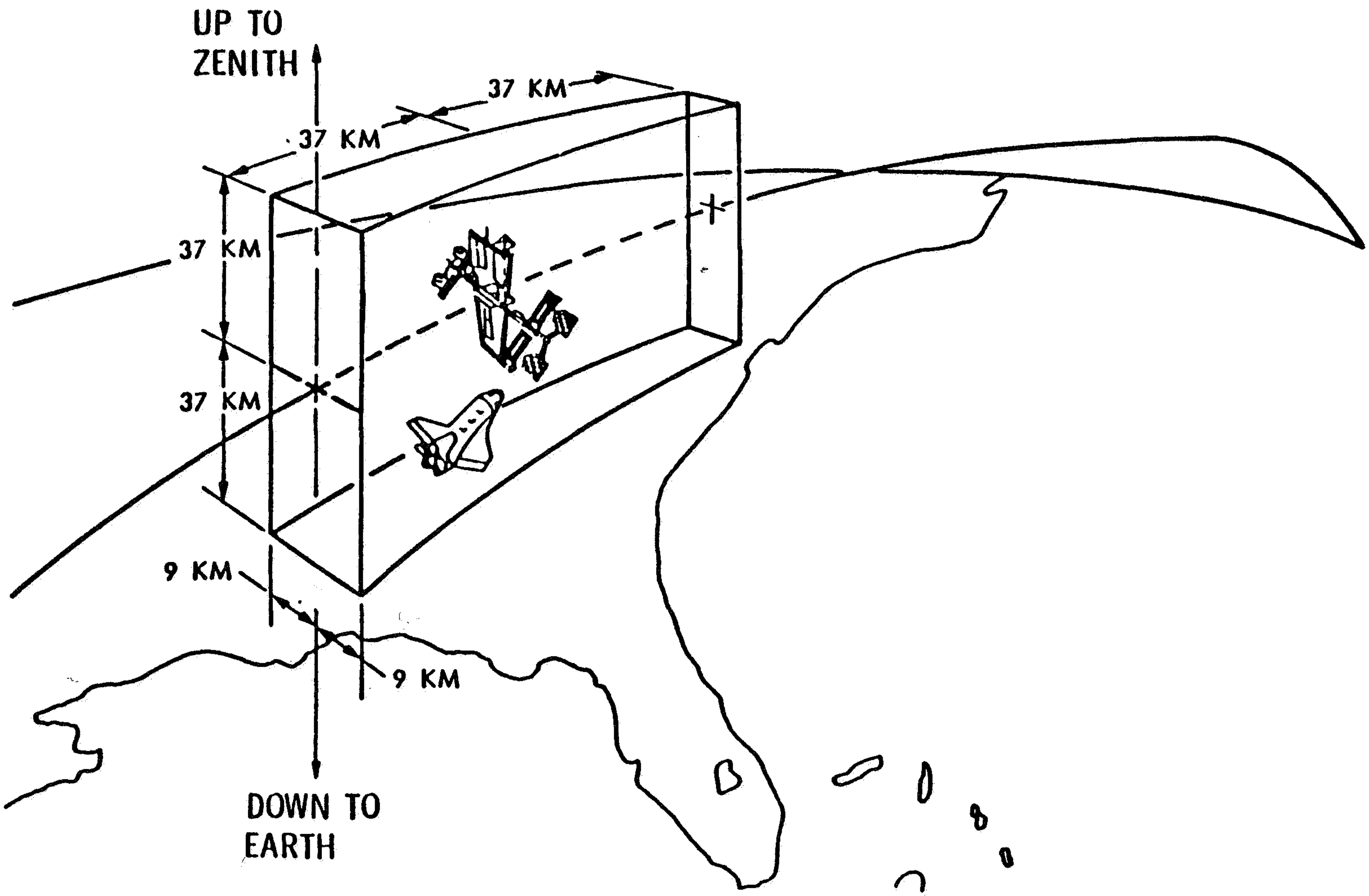
A Command and Control Zone (CCZ), shown in Figure 15, will be established around the Station. It will reach to 37 km behind, above and below the Station and 8 km on each side of the orbit plane. In this zone, the Station will control approaching unmanned vehicles, such as an OMV. Within about 1 km, the Station will control EVA operations and the FTS. The EVA operations are slated to use UHF as now done with the NSTS Orbiter. The FTS communications would be at Ku Band (separate from TDRSS) to provide the necessary bandwidth for video channels used for controlling FTS. Both these frequency choices face regulatory problems; there is potential interference from DOD transmitters at UHF, and from commercial satellite ground transmitters at Ku Band. OMV control is a growth capability.

The main growth path for C&T would be to utilize the planned capability for the Advanced TDRSS at 600 Mbps in Ka Band where the greater bandwidth is available. Also, the cluster communication would move to Ka Band where a primary allocation can be expected and interference from ground station transmitters minimized. There also is potential for optical communications that would expand the data rates while at the same time avoiding regulatory and interference issues. For the video subsystems it probably will be necessary to evolve to whatever High Definition Television (HDTV) standards emerge in the nineties.

The tracking role in C&T will be provided by the Global Positioning System (GPS). This DOD system will be operational using a total of 24 satellites in orbits at about 10,000 nmi. The high accuracy position, velocity and time reference data enable autonomous operations for Station. In addition, GPS will be particularly useful in rendezvous operations where a differential GPS scheme can be used for highest accuracy when the approaching vehicle also has GPS capability. A challenge is to obtain the assured access to GPS with a design that minimizes the program impact of DoD security requirements.

FIGURE 15
COMMAND AND CONTROL ZONE

FREEDOM



GUIDANCE, NAVIGATION AND CONTROL (GN&C) SYSTEM

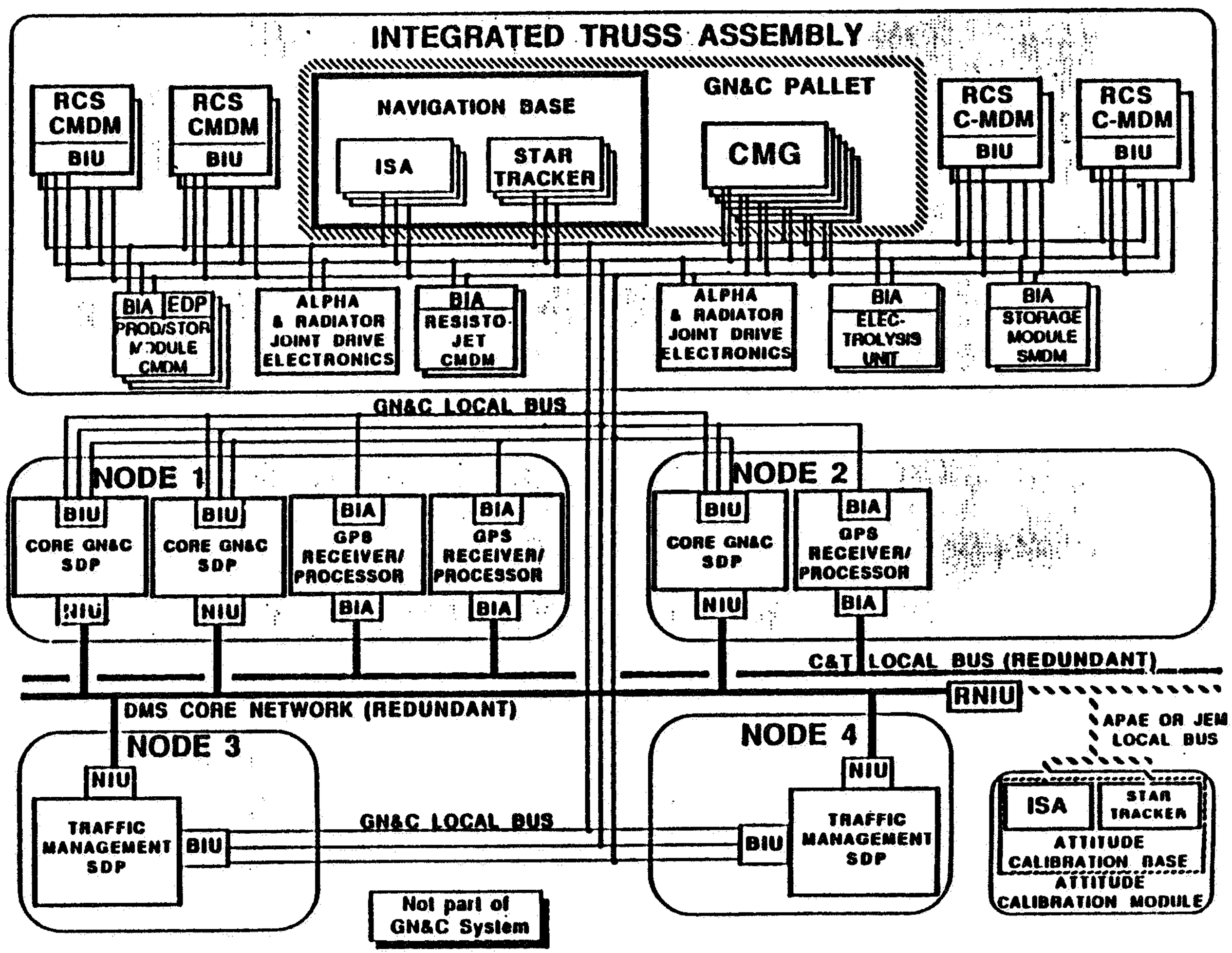
The GN&C System controls the Station attitude, controls reboost, determines pointing angles for the solar arrays, thermal radiators, and antennas, and controls vehicle traffic around the Station. The GN&C System architecture is shown in Figure 16. Major components include star trackers, inertial sensor assemblies, and control moment gyroscopes mounted on a navigation base. Also included are electronics to control: reaction jets, a resistojet for reboost, the truss alpha joints and the thermal radiator beta joints.

In addition to the traffic management function involving control and/or monitoring of vehicles in the control zone, as described earlier, the GN&C controls docking and berthing operations, and collision avoidance maneuvers. The latter includes maneuvers to avoid space debris that is predicted to be on a collision course with Station. The requirements for collision avoidance need to be established and the possible role of on-board sensors needs to be studied.

The Station flies in a local-vertical, local-horizontal (LVLH attitude, keeping the truss perpendicular to the flight direction) within 5 degrees. A torque equilibrium attitude (TEA) strategy is used to minimize attitude control torque over an orbit. A key requirement is to maintain an attitude such that a microgravity environment is established to meet materials science experiment requirements.

Understanding the interaction between control and structure to arrive at an acceptable overall system that meets the needs for stability and microgravity will be a challenge. Perhaps the major challenge is to provide a system capability that evolves successfully through the many stages of the Assembly Sequence.

FIGURE 16
GN&C SYSTEM ARCHITECTURAL HARDWARE SCHEMATIC



AUTOMATION AND ROBOTICS (A&R)

The Station program is committed to the use of A&R technology both in the Station's operation and evolution. The importance of this thrust has been emphasized by recent program reviews that have revealed significant potential shortfall in the ability of EVA alone to maintain the external hardware. There also is a premium on IVA so that as much of this resource as possible is available for experiments.

The avionics systems will make substantial use of automation to manage the control and scheduling of resources in power, communications, momentum control and data flow. In addition, there will be extensive use of automated failure detection and isolation for all systems, and also for recovery in the case of time critical systems.

There are two key robotic systems that have been noted earlier: the FTS and the MSS. The FTS will be able to perform the following tasks:

- Install and remove truss members
- Install a structural interface adapter on the truss
- Changeout Orbital Replacement Units (ORU)
- Mate the thermal utility connectors
- Assemble the thermal radiators

The robotic components of the MSS are the Space Station Remote Manipulator System (SSRMS) and the Special Purpose Dexterous Manipulator (SPDM). The SSRMS provides the following functions:

- Assist in assembly and external maintenance
- Maintain attached payloads
- Transport hardware and payloads about the Station
- Retrieve and deploy free-flying satellites and platforms

- Berth/deberth the Shuttle Orbiter

The SPDM will provide a dexterous capability to reduce and complement the crew's EVA's. The SPDM will be able to:

- Connect and disconnect utilities
- Attach/detach interfaces and covers
- Mate/de-mate connectors
- Provide lighting and closed circuit TV monitoring of work areas for EVA and IVA crews
- Clean surfaces
- Inspect and monitor areas of difficult access
- Manipulate small payloads without standard grapple fixtures

INTEGRATION AND VERIFICATION

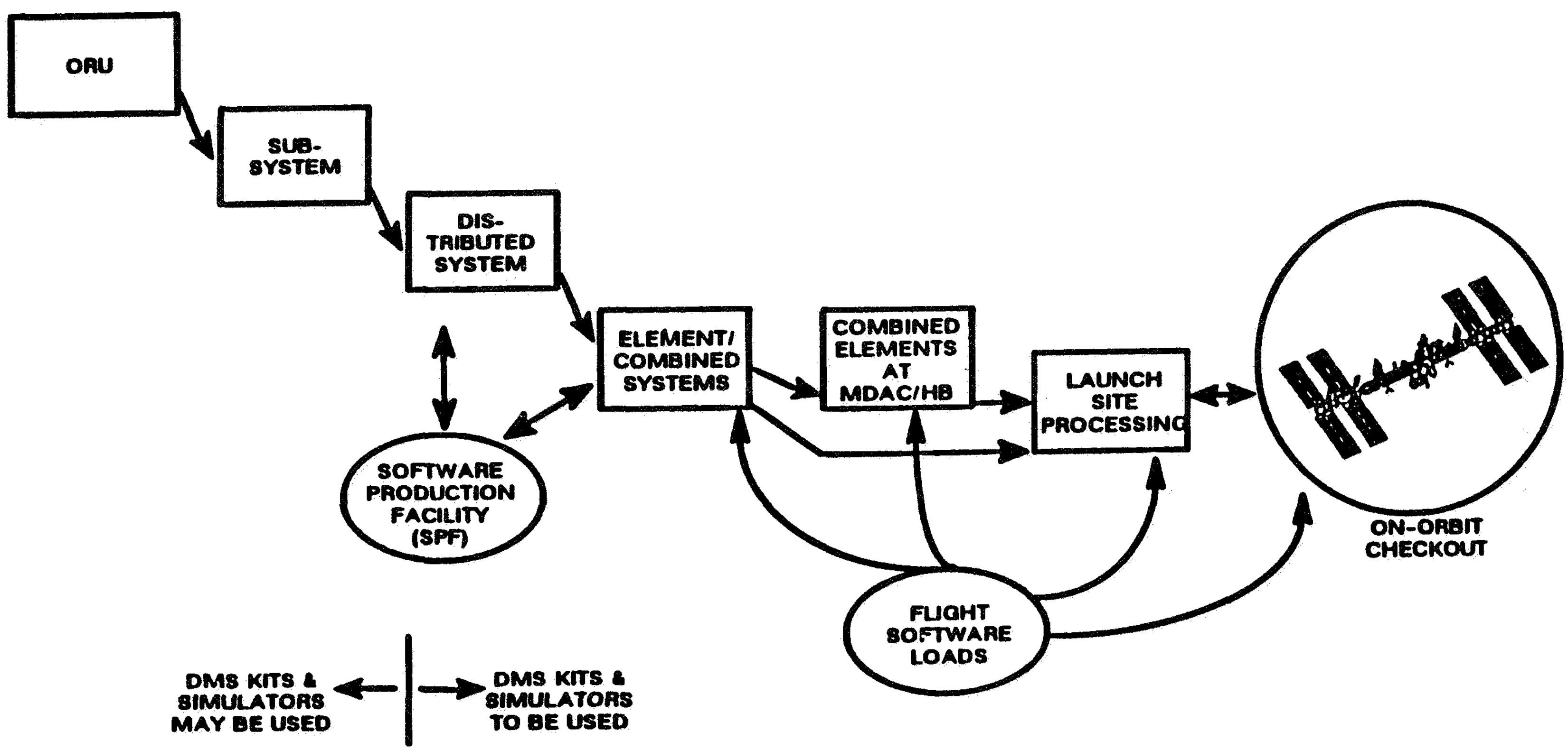
Verification is the process that will confirm that the Station's hardware and software meet all of the design requirements specified. This is particularly important because unlike previous space programs, the Station cannot be completely checked out on the ground prior to launch. Due to its size, the Station will have to be launched in segments and assembled on-orbit as described earlier. To help ensure the successful completion of the assembly, and its operational safety while it is being assembled and operated, it is vital that critical testing be done on the ground before its segments are launched. An overview of the integration and verification process is given in Figure 17.

The flight hardware will initially be built in small units, such as ORU's, and then assembled into larger and larger units, until finally they are assembled into a launch package at the Kennedy Space Center (KSC). Throughout this process, the units will be tested to verify their compliance with the requirements. The initial testing will be

FIGURE 17
SYSTEM ENGINEERING & INTEGRATION

FREEDOM

OVERVIEW OF I & V FOR THE SSP



done at contractor and subcontractor facilities all over the country, as well as in Europe, Japan and Canada.

Final testing will be accomplished at the contractor's facility for the EPS, at JSC for the Truss Assembly, and at MSFC for the Lab and Hab Modules. At the JSC facility, shown in Figure 18, the first few launch packages will be assembled together and checked out, using both flight hardware and simulators. This ground test will significantly increase confidence that Station can be successfully assembled and operated on-orbit. Once the tests are complete, then the individual launch packages will be shipped to KSC for final checkout and launch. All other launch packages will be shipped directly to KSC from their assembly sites.

After the Lab and Hab Modules are checked out at MSFC, they also will be shipped to KSC for final checkout and launch.

Once the launch package is on-orbit, it will be assembled and attached to the Station. Then, it will be checked out to verify its operational readiness. This will include verifying that it can be operated in an unmanned mode, and that manned operations could be subsequently resumed after its' unmanned mode.

Like the flight hardware, the flight software will also be checked out during a series of tests as the software is assembled into larger and larger units. In its early phases, the software will be checked out at a contractor's or subcontractor's facility. For example, software residing in an ORU will be verified when the ORU is tested. The contractors and subcontractors will develop the flight software at Software Production Facilities (SPF's) all over the country, as well as in Europe, Japan and Canada. NASA will provide Data Management System (DMS) kits to integrate the contractor's hardware and software. The DMS kits will emulate the interface between the contractor's hardware and software and the DMS.

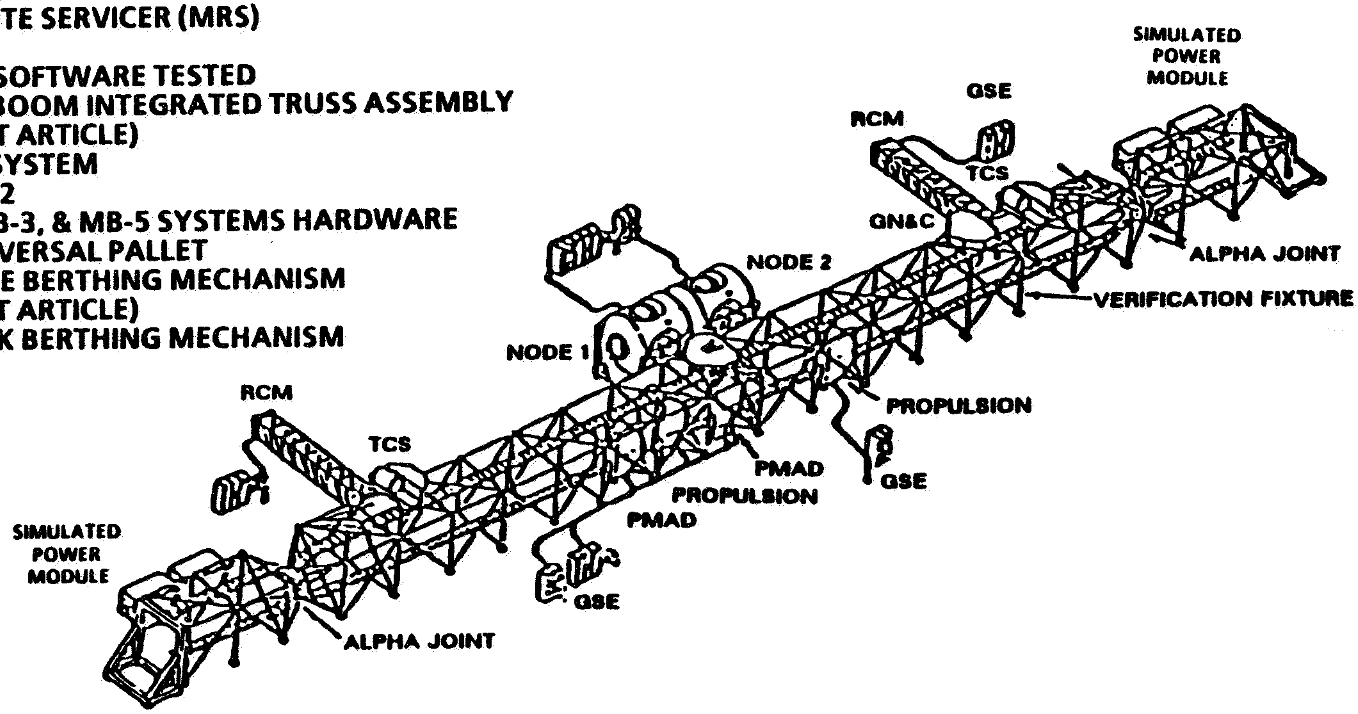
FIGURE 18
SYSTEM ENGINEERING & INTEGRATION

FREEDOM

INTEGRATED TRUSS ASSEMBLY VERIFICATION

HARDWARE SIMULATED
- FLIGHT TELEROBOTIC SERVICER (FTS)
- POWER MODULE
- MOBILE REMOTE SERVICER (MRS)

FLIGHT HARDWARE/SOFTWARE TESTED
- TRANSVERSE BOOM INTEGRATED TRUSS ASSEMBLY (GROUND TEST ARTICLE)
- PROPULSION SYSTEM
- NODES 1 AND 2
- MB-1 THRU MB-3, & MB-5 SYSTEMS HARDWARE
- PAYLOAD UNIVERSAL PALLET
- NODE/MODULE BERTHING MECHANISM (GROUND TEST ARTICLE)
- NODE/AIRLOCK BERTHING MECHANISM



At present, there are no plans for a single facility to integrate the entire flight software package that will be on-board any given flight configuration. The need for such a facility remains to be established.

RELIABILITY, MAINTAINABILITY, AND REDUNDANCY

Reliability and maintainability features of the avionics complement will be especially important in that they will govern the availability of equipment on-orbit, dictate the burden for maintenance levied on the crew and robotics, and impact the logistics resupply flights by NSTS. The current estimate is up to eight NSTS flights per year will be needed for the logistics functions and crew rotation.

An appropriate ORU configuration will be determined for each system considering failure rates and capabilities of both crew and robotics, with emphasis on the latter for external equipment. There will be assessments of reliability and maintainability, but there are no contractual requirements in this area.

Supporting the product assurance effort is an Electrical, Electronic, and Electromechanical (EEE) parts policy that dictates Level S parts or equivalent for critical functions, and recommends Level S for other functions. Involving these requirements in the beginning of development should in many cases avoid the major costs that NSTS experienced in levying higher EEE part reliability requirements on existing designs.

The redundancy policy requires two-fault tolerance for crew safety and Station survival and single-fault tolerance for mission critical support. There is no requirement for other functions. The level of redundancy must be determined prudently for each function, because additional hardware raises the overall failure rate and adds burden to the maintenance function. Unlike what is possible for the NSTS, this burden must be dealt with on-orbit.

EVOLUTION

The planned operational lifetime of 30 years necessarily implies that an evolution capability should be an important requirement. The baseline configuration is to have the hooks and scars to make this capability possible. An important evolutionary path for the Station would be to support two critical functions for the Human Exploration Program. Station would primarily serve as an integrated transportation node providing facilities for vehicle assembly, testing, processing, and post-flight servicing, as well as providing crew support (including IVA and EVA), data management and communications, and logistics to accomplish these activities. It would also provide the resources necessary to verify the research and technology required to support the new initiative. Much of this research and development has to be performed and tested in the space environment; activities which are ideally suited to the Station. The technology development and research areas are broadly categorized as In-Space Operations, Humans in Space, Spacecraft Design Technology, and Lunar/Mars Mission Simulation. A concept for the transportation node building on the dual keel configurations was shown earlier in Figure 8.

RECOMMENDATIONS

Advances in avionics technology can help meet the challenges that have been noted for Station. Some of these challenges are summarized in Figure 19. Since Station will continue to evolve, improvements could be introduced when ready. The most critical areas appear to be those that would make more power and crew time available to users. This implies more efficient power generation, distribution and management, and greater power efficiency for all avionics with particular attention to DMS components. Crew time can be freed up for users with greater application of A&R, including artificial intelligence and expert systems, and by providing a high level of inherent reliability.

FIGURE 19
AVIONIC SYSTEMS CHALLENGES

AREA	CHALLENGE
Electric Power	DC Switchgear Development Evolution to Solar Dynamic & AC power
Data Management	Complexity Verification
Communication and Tracking	End-to-End Definition Regulatory Environment Evolution to Ka Band & HDTV
Guidance, Navigation, Control	Assembly Sequence Structural Interaction Microgravity Collision Avoidance
Automation and Robotics	Significant Assembly & Maintenance Role
General	Power Efficiency Reliability Maintainability Upgrades & Evolution

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CREW EMERGENCY RETURN VEHICLE (CERV) AVIONICS

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM

WILLIAMSBURG, VA.

NOVEMBER 7-9, 1989

ASSURED CREW RETURN CAPABILITY
CREW EMERGENCY RETURN VEHICLE (CERV) AVIONICS

WHITE PAPER

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CERV SYSTEMS INTEGRATION

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WHITE PAPER

Harvey Dean Myers
JSC-IA131
CERV Systems Integration

September 14, 1989

Background

NASA is currently investigating a Crew Emergency Return Vehicle (CERV) to provide assured crew return for Space Station Freedom. While the Space Station, in conjunction with the Space Shuttle, is capable of handling many emergency situations on its own, NASA has found at least three situations where a CERV is essential:

- Medical Emergency - Provide the crew with the ability to evacuate seriously injured/ill crewmember from the Space Station to a ground based care facility under medically tolerable conditions.

- Station Catastrophe - Provide the crew with the ability for a safe and time-critical evacuation of the Space Station in the event the Space Station becomes uninhabitable.

- Shuttle Problems - Provide the crew with the ability to return safely to Earth from the Space Station in the event NSTS flights are interrupted for a time that exceeds Space Station ability for crew support and/or safe operations.

The NASA Phase A investigations over the past several years identified the above requirements and they have been documented as Design Reference Missions 1, 2, and 3 respectively (DRM's 1, 2, 3) within the CERV Systems Performance Requirements Document (SPRD), JSC 31017.

The CERV SPRD has been prepared as functional and performance requirements in such a manner as to minimize design specificity of the requirements. The CERV Project intent is to identify the minimum set of requirements that will enable the project objective of a simple, reliable, cost effective vehicle and give the contractor maximum design freedom. The CERV Phase A'/B procurement effort, currently scheduled to begin October 2, 1989, is intended to affirm the existing project requirements or to

amend and modify them based on thorough evaluation of the contractor(s) recommendations.

The CERV design must be capable of simple, nearly automatic operation because its control will probably be by a physically deconditioned crew. Therefore, although crew intervention may be required, it is not envisioned that CERV operation will require highly trained piloting skills to operate the CERV for separation, deorbit, entry, and landing activities.

The CERV must be available for immediate use throughout the life of the Space Station. Therefore, reliability is an important design requirement for the CERV. If the CERV is to be a highly reliable vehicle, the onboard systems must to be simple, and use proven state-of-the-art technology, with robust design margins and sufficient systems redundancy to be available for immediate use.

Long periods of dormancy are a desirable design objective. Dormant systems exhibit higher reliability than those that are active. However, establishing confidence in the CERV System may require periodic systems health check tests and evaluations. These periodic system health checks would be made utilizing the CERV avionics hardware/software systems in conjunction with the Space Station and must be capable of diagnostic isolation of a failed system to the ORU level. This implies, among other things the of sharing some limited resources with the Space Station, e.g. power, ECLSS, communications, personnel, etc..

To enhance CERV System reliability while minimizing life cycle costs, it will be a Program goal to embed CERV operations within existing, ongoing programs such as NSTS and Space Station Freedom. Launch and delivery of the CERV to Space Station Freedom will be accomplished using existing NSTS and ELV capabilities. Once at the Space Station, CERV activation, periodic checkout, and maintenance will become an integrated part of the Space Station workday activity, although with minimal interference to ongoing productive activities. On the ground, existing facilities and personnel at KSC will largely suffice for prelaunch processing, logistics, and turnaround operations. The highly flexible workstations and reconfiguration environment currently under development at JSC for the NSTS and Space Station Control Centers will enable those facilities to accommodate CERV mission planning and real-time support. And finally, a vital link in the operations concept will be provided by reliance upon existing worldwide Search and Rescue capabilities, both U.S. and international.

The JSC CERV Project Office, during its in-house Phase A studies, evaluated the following four CERV concepts (shown in figure 1): a) The Reference Configuration, b) The Benchmark Configuration - SCRAM, c) The Apollo Derivative, and d) The LaRC Lifting Body Configuration.

NASA
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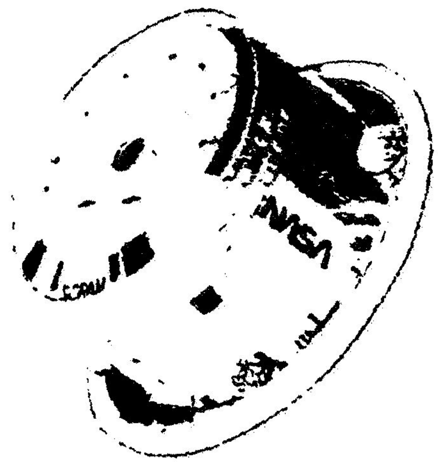
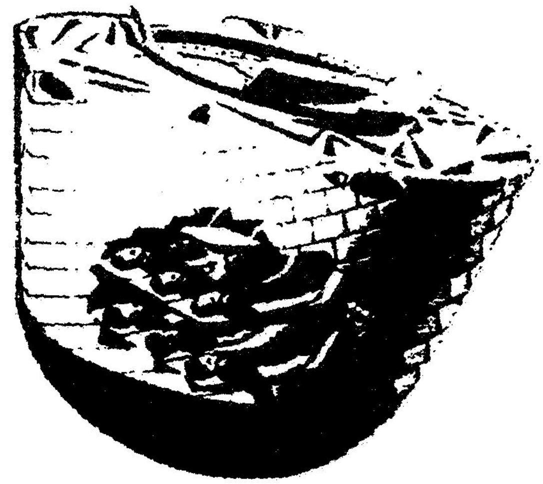
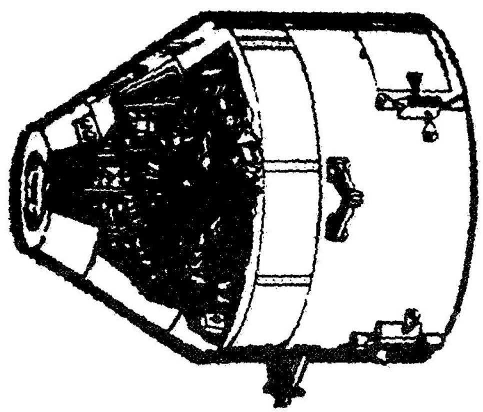
Candidate CERV Vehicle Approaches



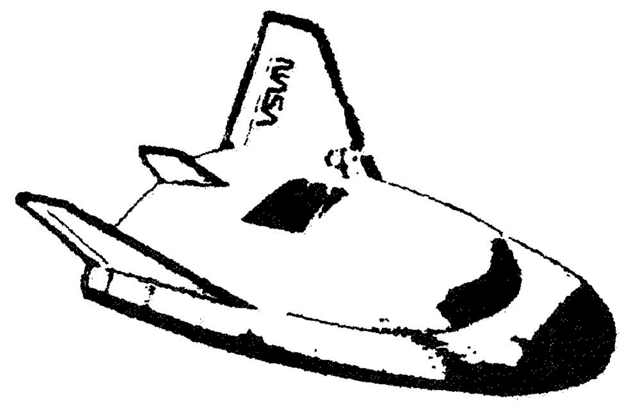
SCRAM VEHICLE



DISCOVERER SHAPED VEHICLE



APOLLO DERIVED VEHICLE



MID - L/D VEHICLE

FIGURE 1. CERV PHASE A STUDY CONFIGURATIONS

The following treatment of the CERV avionics systems is presented with the caveat that a firm CERV system design has not been selected at this time. The following discussion in not to be construed as expressing a preferential avionics system/subsystem configuration by the JSC CERV Project Office.

For the purposes of this symposium the reference configuration concept avionics systems will be presented.

CERV Avionic Systems

The avionics systems design is required to perform the three DRM's with minimal crew participation. It is assumed that the crew will have limited training in CERV operations, as well as being in a physically deconditioned state. The crew may participate in some simple operational functions; however, those functions that require skilled piloting capabilities will be automated.

Another avionics systems design goal is availability. Availability dictates a fail-safe avionics system/subsystem that will be backed up by redundancy in critical systems, by other systems/subsystems automatically, or by limited crew participation.

Space Station emergencies, DRM2, place the most severe requirements on the avionics system/subsystem. The CERV must be in a safe configuration and ready for departure within minutes after a Space Station emergency is declared and it is determined that crew evacuation is required. This condition will allow minimal planning, warmup, and checkout time.

The avionics hardware design objectives will be to comply with the Space Station interfaces and possess some degree of ORU commonality. The ORU commonality is desireable from the CERV standpoint to the extent that simplicity and reliability is not compromised.

The JSC CERV Project Office Phase A reference configuration concept evaluations identified the following systems:

Guidance, Navigation, and Control
Displays and Control
Communication and Tracking
Electrical Power
Propulsion
Pyrotechnic
Environmental Control and Life Support
Thermal Protection
Medical
Landing and Recovery

Of these systems the first four are considered to make up the avionics systems. The remainder are integrally related to the avionics in the demand-command response sense.

The system contains dual avionics strings for redundancy. Two General Purpose Computers (GPC's) with their associated software and Multiplexer/De-Multiplexers (MDM's) comprise the heart of the system, essentially the Data Management System (DMS). The GPC's will run simultaneously but not synchronously. The primary GPC will be in control of system operation until a fault is detected; then it will be automatically switched to the secondary GPC. Individual ORU's will be selected or deselected automatically by the GPC's. Fault detection logic to select other systems/subsystems will also be contained in the GPC's to operate similarly to the above fault selection subsystem. Manual override will be possible through keyboard entries. Dual MDM's will be used to interface the other GN&C subsystems and Reaction Control System (RCS) jet drivers to the GPC's. The dual Inertial Measurement Units (IMU's), dual Horizon Sensors and Global Positioning System (GPS) will also be interfaced to the GPC's through the MDM's. Sensor data, including medical, will be linked through the MDM to the GPC for onboard decision-making or for downlink to the ground by the S-band.

A single-string GPS system could be used to obtain the state vector for CERV, especially in the DRM-2 application. Where time permits prior to Space Station separation, the CERV state vector initialization will be obtained by an exchange of information with the Space Station. The backup for acquiring a state vector will be the single-string S-band with telemetry and command uplink capability. A state vector can also be entered manually via the keyboard.

Guidance, Navigation, and Control (GN&C)

The GN&C system block diagram is shown in figure 2. The system possesses the following characteristics:

- 0 Two strings with cross-strapping between units
- 0 Strings consist of:
  - General Purpose Computers
  - Multiplexers/De-Multiplexers
  - Inertial Measurement Units
  - Horizon Scanner
  - Reaction Jet Drivers (RJD's)
- 0 Horizon sensors and gyrocompassing are used for attitude alignment
- 0 Sensors provide systems information to the GPC's for systems control and/or for use with communications or telemetry
- 0 The GPC's provide control to most of the CERV systems/subsystems

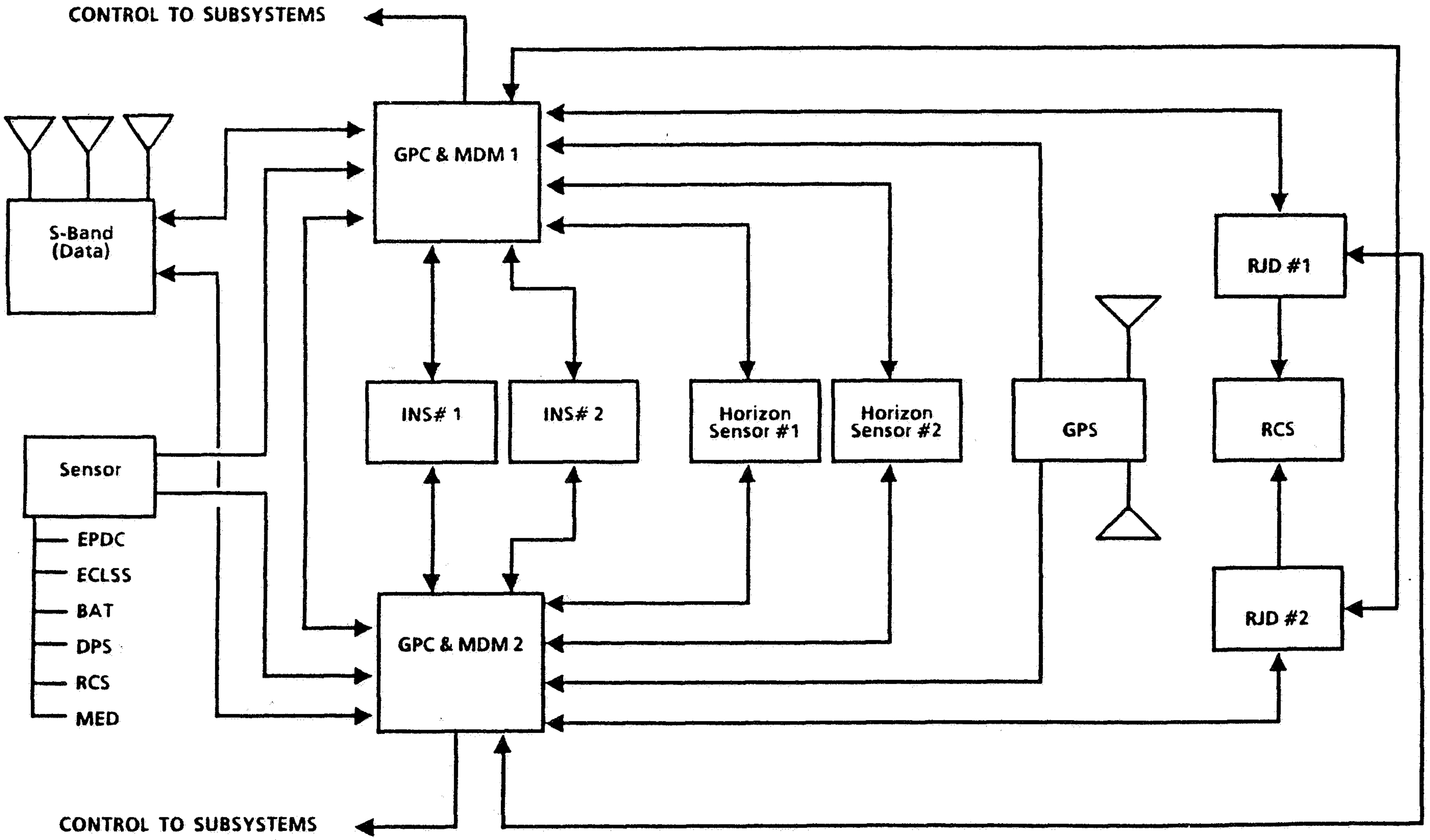


FIGURE 2. GN&C SYSTEM

CERV Software

The CERV software will be developed independently of the Space Station software; however, in keeping with aforementioned embedded operations, its development may use the existing Space Station Program rules and tools, e.g. Software Support Environment (SSE). Space Station software interface criteria will be satisfied such that periodic health test checkout and evaluations can be performed. The software subsystem will control the sequence of the startup and shutdown of CERV systems/subsystems and will provide GN&C for Space Station separation, landing site targeting, deorbit maneuvers, reentry control, and landing.

Since this software is designed for an emergency vehicle, there should be no constraint on its use in unexpected situations. The software will also support the fault detection and isolation functions. For durability, reliability, and quick activation, the software may be put into the read only memory (ROM) of the GPC's. Provisions for updating the CERV software will be included. For example, the CERV is currently thought to interface to the Space Station resource nodes one and three, top ports. Should the Space Station configuration change such as to impact the CERV location and departure trajectory, then the CERV GN&C will have to change.

Displays and Controls

The Displays and Controls (D&C) subsystem is designed to minimize the crew interface but to allow some manual override if necessary. Manual override will not be required but will support system reconfiguration if such is required. Manual control will be allowed for noncritical systems based on cost, training factors, and subsystem complexity. In keeping with the philosophy of minimizing crew interface and training, no hand controls are provided for vehicle maneuvering.

The primary interface between the crew and CERV subsystems may be electroluminescent (EL) screens and keyboards. These units will be used to monitor subsystems, display information, and provide inputs to the GPC's. Reconfiguration of the avionics and communications subsystems can be accomplished manually if so desired. The crew will also have access to switches and circuit breakers for manual override in limited circumstances. A caution and warning display and master alarm will be provided to enhance safety. A fire detection and suppression system will also be provided.

Manual control will be provided for a portion of the ECLSS related to crew comfort and for lighting. The UHF communications subsystem will be manually controlled by the crew. The Search and Rescue Satellite (SARSAT) system will be controlled by the GPC's.

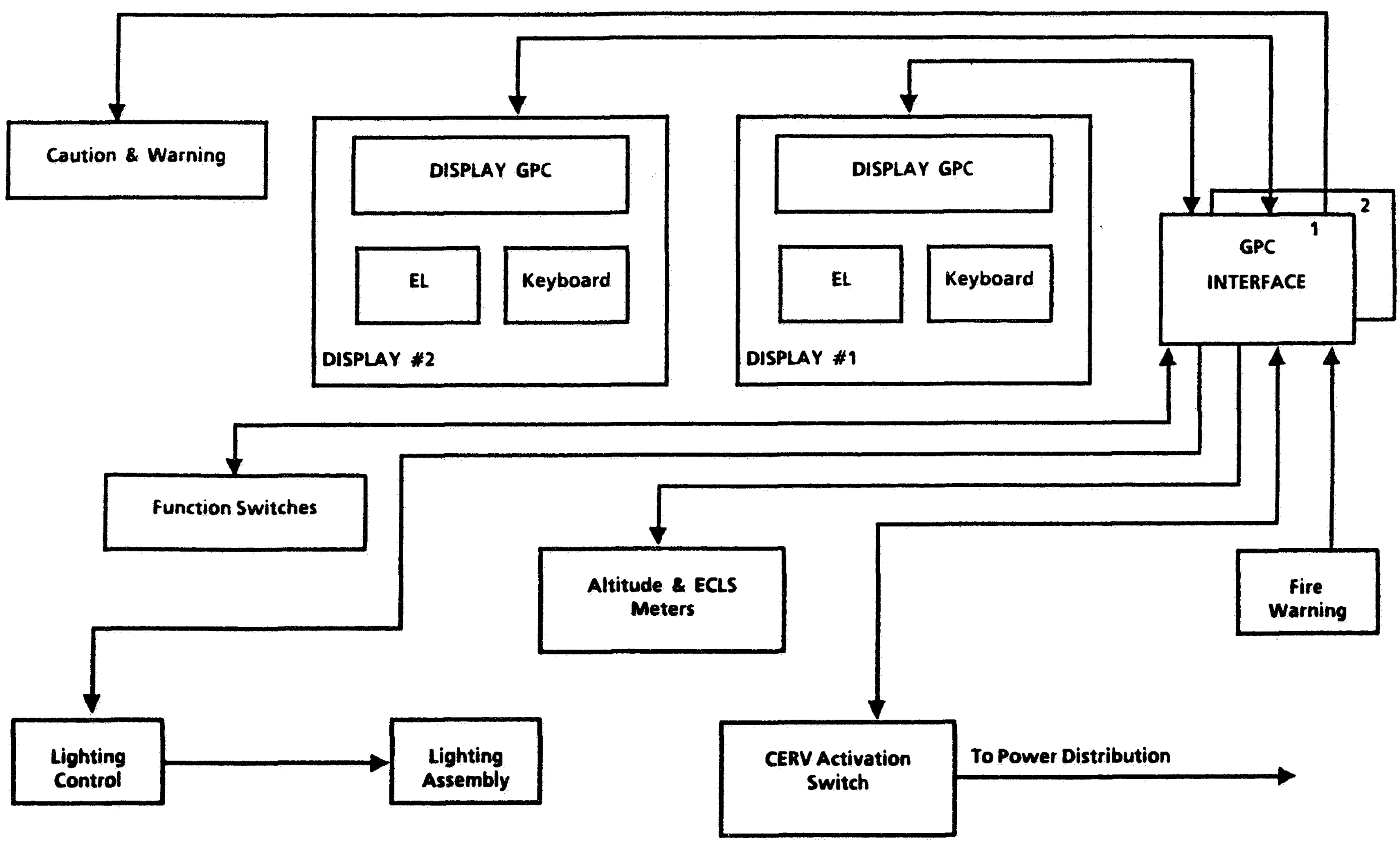


FIGURE 3. DISPLAYS AND CONTROLS SYSTEMS

The D&C system is completely redundant and is derived from the Space Station work station. It contains an embedded processor to relieve the GPC of the task of formatting and displaying data. The similarity to the Space Station work station will minimize CERV training. Figure 3 is an example of such a display and control subsystem.

Communications and Tracking

The communications subsystem will be a single-string subsystem with the redundancy provided by other backup subsystems. The communication subsystem will be automatically controlled by the CERV GPC with manual override by the crew being provided through the D&C keyboard. The UHF subsystem, except for the SARSAT beacon, will be manually controlled by the crew and will be the backup voice communications subsystem. The SARSAT beacon is controlled by the GPC. A voice intercom subsystem will be provided to the Space Station audio subsystem. Data communication with the Space Station will be provided through a direct interconnect between the CERV MDM's and the Space Station data busses.

The Global Positioning System (GPS) receiver, which will have redundant antenna selected by either the GPC or manually by the crew, will provide direct inputs to the GPC for the state vector. The GPS will be the primary source of state vector with backup being provided by the Space Station or the ground through the S-band subsystem.

The single-string S-band subsystem will have three antennas selected by either the GPC or manually and will be the primary voice, telemetry, and command uplink subsystem. The voice subsystem will have the UHF subsystem for backup but the telemetry and command subsystem will have no backup. A failure of this subsystem would not endanger the CERV mission.

Power

The power subsystem as conceived for the reference configuration is a lithium-bromine complex (LI-BCX) battery pack. The size and weight of the CERV batteries have been determined based on the requirements of the minimum weight and volume, minimum on orbit maintenance, minimum turn-on time at time of use, and redundancy. Although a 4-year shelf life is desired, shelf life data for this subsystem is only available for two years. It is anticipated that shelf life data to support the 4+ years shelf life will be available by the mid-1990's. Storage temperature of zero degrees Fahrenheit would enhance storage life.

Power safety plugs complete the circuit between power busses and controllers when installed after the CERV is berthed to the Space Station. This ensures no battery drain prior to connection to the main power controllers.

The Electrical Power Distribution Subsystem (EPDS) is conceived to be designed for single fault tolerance and to be capable of providing the energy needed for the CERV mission. Two separate power controllers will distribute power even if a battery subsystem or controller fails. The individual power controllers can be switched to the other battery bus for additional redundancy.

The CERV GPC will provide automatic control and fault detection for the EPDS. Essential power from each battery bus will provide power to the GPC's and MDM's. Power to these subsystems can also be provided through the main buses. Figure 4 depicts the Electrical Power System.

Another battery concept of interest is the Lithium Reserve Battery. In this application the battery electrolyte is stored in a separate reservoir until the CERV is required to be activated for a mission. Upon activation the electrolyte is injected into the battery cells. This approach provides long-term on orbit storage without voltage degradation and minimizes battery thermal requirements. This concept, however, would require Space Station power for periodic test and checkout of the CERV.

Summary

The Crew Emergency Return Vehicle (CERV) is being defined to provide Assured Crew Return Capability (ACRC) for Space Station Freedom. The CERV, in providing the standby "lifeboat" capability, would remain in a dormant mode over long periods of time as would a lifeboat on a ship at sea. The vehicle must be simple, reliable, and constantly available to assure the crew's safety. The CERV must also provide this capability in a cost-effective and affordable manner.

The CERV Project philosophy of a simple vehicle is to maximize its useability by a physically deconditioned crew. The vehicle reliability goes unquestioned since, when needed, it is the vehicle of last resort. Therefore, its systems and subsystems must be simple, proven, state-of-the-art technology with sufficient redundancy to make it available for use as required for the life of the program.

The CERV Project Phase A'/B Request For Proposals (RFP) is currently scheduled for release on October 2, 1989. The Phase A'/B effort will affirm the existing project requirements or amend and modify them based on a thorough evaluation of the contractor(s) recommendations. The system definition phase, Phase B, will serve to define CERV systems and subsystems. The current CERV Project schedule has Phase B scheduled to begin October 1990. Since a firm CERV avionics design is not in place at this time, the above treatment of the CERV avionics complement for the reference configuration is not intended to express a preference with regard to a system or subsystem.

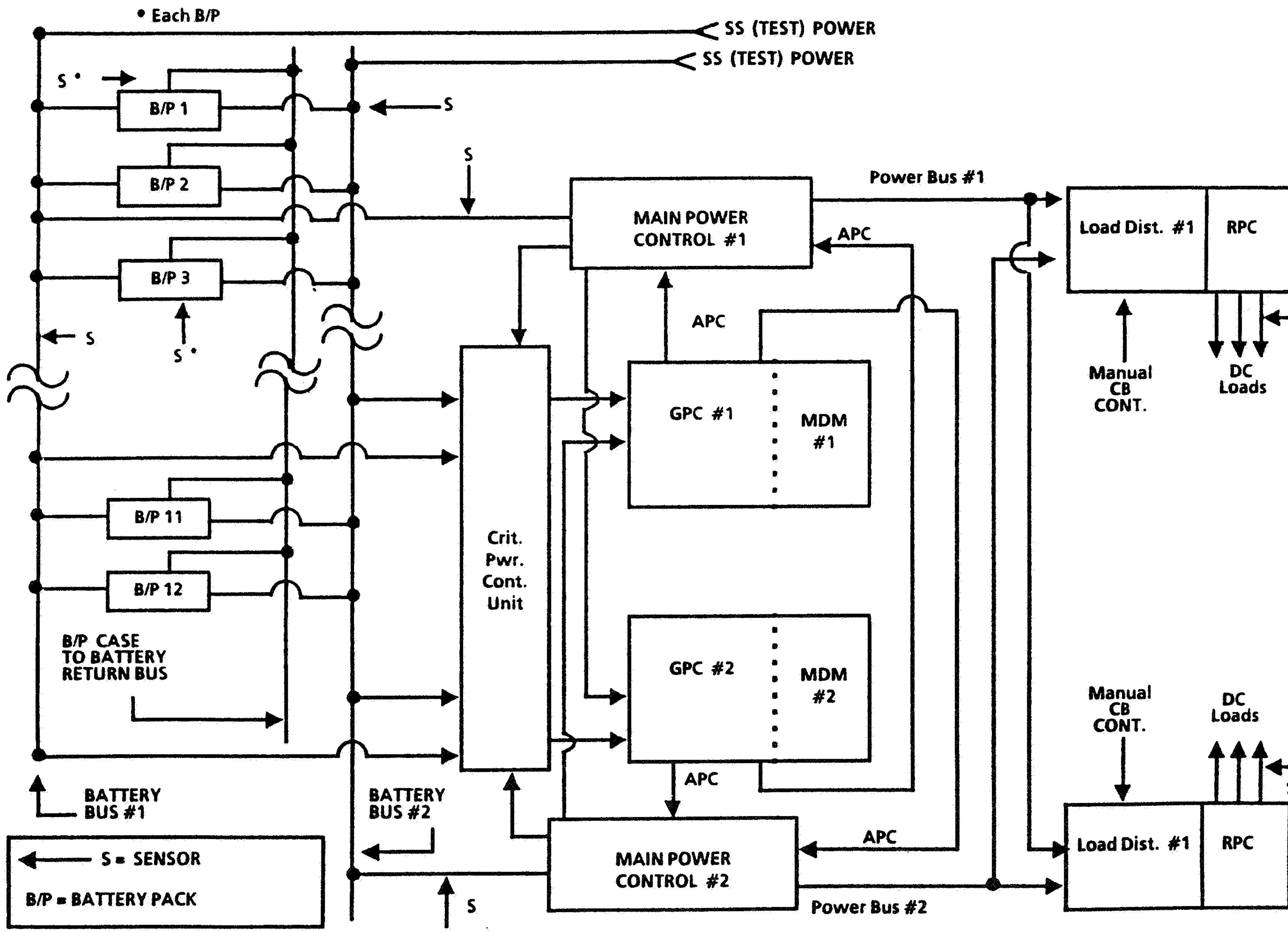


FIGURE 4. ELECTRICAL POWER SYSTEM

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SPACE TRANSFER VEHICLE AVIONICS ADVANCED DEVELOPMENT NEEDS

SPACE TRANSFER VEHICLE AVIONICS ADVANCED DEVELOPMENT NEEDS

C. F. HUFFAKER
MSFC / PT31

PROGRAM DEVELOPMENT
SPACE TRANSPORTATION AND EXPLORATION OFFICE
UPPER STAGE GROUP

NOVEMBER 7, 1989

INTRODUCTION

President Bush on July 20,1989 announced the mandate to NASA to prepare a sustained planetary exploration plan for the 1990-2020 period. The plan covers the Mission to Planet Earth and S.S. Freedom programs during the 90's, return to the moon and creation of a manned Lunar outpost during the first decade and a manned outpost on Mars in the second decade of the 21st century. The task of moving explorers and their equipment and science experiments between the surfaces of the Earth and the Moon and Mars will place a heavy demand on the performance, reliability, maintainability and flexibility of the transportation system. In order to effectively meet these demands, early designs will focus on the Lunar mission needs. The resulting space transfer vehicle core system will first obtain flight experience by flying Planet Earth, precursor and other unmanned planetary missions followed by manned Lunar and then, evolve to the more complex manned Mars missions before 2020. This approach maximizes the commonality and synergism between the Planet Earth, Lunar and Mars missions and brings the challenge of transportation for the exploration initiatives well within the reach of orderly technology advancement and development.

PROJECT DESCRIPTION OVERVIEW

The assessment of preliminary transportation program options for the exploration initiative is underway. The exploration initiative for Lunar and Mars is outlined by mission phases in Figure 2. A typical Lunar/Mars Outpost technology /advanced development schedule is shown in Figure 3. An aggressive and focused technology

development program is needed as early as possible to successfully support these new initiatives. This paper will describe the avionics advanced development needs, plans, laboratory facilities and benefits for an early start.

The Lunar transportation system consists of the Lunar transfer vehicle (LTV) and the Lunar excursion vehicle (LEV) shown in Figure 4. Although designed to be reusable, the LTV will initially be expended in order to deliver heavy payloads during the early emplacement phase. In the steady state mode, the LTV is based at Freedom. Reusable personnel and cargo vehicles will begin operation after initial emplacement operations and continue through outpost consolidation. Once Lunar exploration begins, up to two flights per year will be conducted from Freedom to the Lunar surface.

The LTV is a dual-purpose, 1-1/2 stage design consisting of a propulsion / avionics module core and aerobrake,four expendable main propellant tanks and a Lunar transfer crew module (LTCM). A common vehicle is used for both cargo and piloted missions to the Moon. The LTV with four engines at 20,000 pounds thrust each has engine out capability. The aerobrake is a rigid, spherical, sector-truncated cone structure made of composite materials covered with advanced Shuttle-type thermal protection system (TPS) tiles. The peripheral segments of the aerobrake are attached to the LTV core and aerobrake centerpiece at Freedom and the combination is checked out. The LTV core/aerobrake is then mated to the four propellant drop-tanks and cargo modules are added to complete the Lunar transfer vehicle. Windows and control displays allow the crew to control rendezvous and docking operations. The environmental control and life support system (ECLSS) is a Freedom-derived two gas, open-loop system. Power comes from advanced fuel cells located on the LTV. The module has a galley, zero-gravity toilet, and limited personnel hygiene provisions. The lunar transfer crew module (LTCM) attaches to the LTV and provides support for the crew. Systems operate for 4 days on the trans-Lunar leg and up to 7 days on the inbound leg to earth including a standby period while in Lunar orbit for the nominal Lunar missions. Shuttle-type medical supplies are provided. The LTCM fits within the aerobrake wake envelope of the LTV on return from the Moon and can accept up to a 5-g deceleration.

The LEV consists of a propulsion / avionics module and Lunar excursion crew module (LECM).The propellant system is sized for 30 days on the Lunar surface.The LEV employs common main engines; integral cryogenic thrusters; advanced fuel cells with battery back up for electrical power; advanced, redundant avionics software; and communications systems with the LTV. LEV landing legs and pads are provided with height control for both landing pad

and unimproved landing areas. Multiple communications capabilities for LEV to LTV, Earth, Freedom, Lunar surface, and communications satellites are provided. Automated rendezvous and docking for both LLO and LEO are also provided.The LEV is normally based on the Lunar surface, covered by an environmental shelter, ready for launch and rendezvous with the LTV in the steady-state mode.The LECM, which shares common systems design with the LTCM, transports four crewmen. LECM systems are quiescent except for 4 days during descent/ascent missions. Power comes from fuel cells in the LEV during missions and from the surface support system during quiescent periods on the Moon. The LECM has no airlock; operational EVA's are normally not required. For early Lunar missions and contingencies, EVA's are supported by depressurizing the module. Repressurization gas is provided for two contingency EVA's with options for more if necessary. The LECM can fly at least five Lunar missions with checkout, maintenance, and resupply either in Lunar orbit or on the surface. Figure 5 shows a typical Lunar transfer operations. The vehicle will be capable of launching a crew to other Lunar areas, as the exploration program expands.

Figure 6 shows the Mars transfer operations. The complete Mars vehicle, ready for departure from Earth orbit, consists of a Mars Transfer Vehicle (MTV) with expendable trans-Mars injection (TMI) stage and a Mars Excursion Vehicle (MEV). The Mars vehicles require assembly and launch processing in LEO at Freedom. Assembly of the TMI stage and final joining of the TMI stage to the rest of the vehicle occurs near the station in a co-orbital position. Assembly is performed by robotic postitioning / manipulator arms. EVA is needed only for contingencies and possibly for inspection tasks. The cargo mission uses only the TMI element of the MTV and two MEV's. The MTV is boosted to Mars transfer trajectory by the TMI stage, which consists of a core module with five engines and up to three additional strap-on tank modules.The strap-on tanks are the same configuration as the core module tanks.When this stage has completed its job, it is jettisoned. The MTV has a large aerobrake for Mars aerocapture.The brake may optionally be returned to Earth by the trans-Ear The aerobrake is identical in shape and size to the aerobrake used by the Mars excursion vehicle but uses heavier structure.The MTV crew module is a single pressurized structure with an internal bulkhead to provide redundant pressure volumes. The crew is provided private quarters and exercise equipment, appropriate for the long (up to 3 years) mission duration. Space suits are carried for each of the crew; these suits accompany the crew to the Mars surface and back.

The MEV separates from the MTV before the Mars arrival and uses its own aeroshell for Mars orbit capture. After both vehicles are captured, the vehicles rendezvous and berth together. The crew

transfers to the excursion vehicle for the Mars surface mission and the MEV separates from the MTV for descent to the surface. The crew pilots the MEV from the crew module during descent so that the ascent stage can be immediately activated in the event of an abort. The ascent stage is positioned on the descent stage for liftoff, either from a landing abort or for normal ascent. The MEV descends from Mars orbit to the Mars surface, supports the crew on the surface for up to 20 days, and returns the crew to Mars orbit for rendezvous with the MTV. After a brief checkout of the transfer vehicle, the trans-Earth burn is initiated at the first available opportunity.

The MTV using four advanced space engines that are the same as those used for the Lunar Transfer Vehicle returns the crew to Earth. It has long-duration crew accommodations for the transfers from Earth to Mars and return. It also includes an Earth capture crew vehicle (ECCV), a small Apollo-shaped capsule designed to aerobrake the crew either to low Earth orbit (LEO) or directly to Earth's surface.

The Lunar/Mars Initiative advanced development program will require the development of many systems for the Space Transfer Vehicle as shown in Figure 6A. This paper will highlight an approach for the development of the avionics systems and their associated laboratories and facilities.

AVIONICS ADVANCED DEVELOPMENT CRITERIA / CONCEPT

The criteria and the concept for an avionics advanced development program are shown in Figure 7. Technology and advanced development efforts are performed only where necessary to assure that mission performance can be validated and insight gained to confirm design approaches and reduce uncertainties.Interface standards are established early and problems discovered and solutions worked out in a lower-cost environment prior to the start of full-scale hardware development. The applications of these criteria to all phases of the transportation systems development is critical not only to the Lunar Outpost but also to the development of the Mars Outpost requirements. Technology development provides hardware and concept demonstration early in the life of a vehicle program in order to validate performance,operations and cost. A focused technology program schedules confidence into the follow-on advanced development demonstrations that supports key milestones. This approach helps management choose from identified design alternative or operational concepts. Technology identification, prioritization and planning begins with conceptual studies and trades, continues to support preliminary design and

evolves to full scale hardware development and operations with demonstrations keyed to major decision points.

The key to success is the tight management program control,authority and responsibility under the program manager,with implementation shared by the organization able to perform the invention,development,demonstration,and implementation with credibility.

Based on past experience a major challenge of the new initiative will be to define and stablize system interface requirements between parallel development programs which historically change between each major system during and after the program development phase. The Lunar and Mars Outpost will each require several parallel development programs i.e. ETO,Freedom accommodations, space transfer vehicles and surface systems. The Lunar/Mars transportation system will have parallel development efforts ,i.e. STV,LTV,LEV,and lunar ballistic hoppers.Technology and advanced development,if structured properly, can provide a way to tie down interface requirements before multi-program/contractor interface changes become major issues.

AVIONICS ADVANCED DEVELOPMENT EXAMPLE NEEDS

Avionics advanced development needs are summarized in Figure 8 and are described on Appendix 1 quad chart formats with the description, major tasks, major drivers / benefits, and current technology identified.

The performance examples from the lunar initiative studies include; vehicle avionics(8A), vehicle software (8B), vehicle health management(8C), and autonomous self test and checkout(8D). The Operations examples include: automated vehicle assembly(8E), automated rendezvous and docking(8F), vehicle flight operations simulations(8G) and autonomous landing(8H).

ADVANCED AVIONICS DEVELOPMENT DEMONSTRATIONS

Laboratory and flight demonstrations needed by program phase are shown in Figure 9.

ADVANCED AVIONICS LABORATORY PHILOSOPHY AND OVERVIEW

Historically, R&D laboratories have been designed to develop and test a particular vehicle with limited usage during the early design phase. Consequently, design cycles were encountered for laboratory tools during phases A, B, and C of the vehicle development. Often software designs were rewritten several times before final hosting on the targeted computers simply because of the incompatibility of computer systems. The advancements in workstation capabilities (size, speed and software support systems) makes it conceivable to string together much of the Lunar and Mars vehicle avionics design process not as a cyclic process but as an evolutionary process. The design concept for a new avionics laboratory must recognize the existing and evolving capabilities of computer systems to formulate and integrate all phases of the avionic systems design . As the focal point of the Lunar/Mars advanced transportation avionics facilities, a new advanced avionics laboratory is envisioned as a generalized resource facility providing both existing and new programs with a complete set of tools for the design, development and testing of avionics systems. This laboratory concept should have the following capabilities as described in Figure 10.

The proposed concept shown in Figure 11 is designed to handle the large problem domain of the lunar initiative in real time. It is essential that the laboratory not only handles real-time operations.It must also function as a modeling laboratory, subsystem testbed and implicitly to provide system validation and verification as the Lunar and Mars vehicles design, development and testing progresses.

The philosphy for the proposed laboratory design will be to support the space transportation systems from cradle to grave. This begins with the initial modeling, progresses through real time integration of remote subsystems, to the validation and verification of the avionics system design,and finally sustained flight mission support. Each component in the laboratory design has some commonality to most life-cycle phases of the Lunar and Mars project with the intent of maximizing utilization and minimizing redesign. The four laboratory design phases are summarized in Figure 12 and discussed in more detail in Appendix 2.

BENEFITS OF ADVANCED DEVELOPMENT

Figure 13 lists the benefits of an advanced avionics development program and laboratory. Advanced development clearly validates design approaches and provides confirmation of performance specifications before costly design commitments are made. The proposed development laboratory will reduce development time and risks and provide data for the early resolution of issues and problems. Hindsight has shown the value of timely demonstration data in the support of cost effective decisions throughout the life of a program. The avionics development laboratory will be a new tool for the design and development of avionics systems that will provide continuous and evolving support to all program phases. The laboratory will form the common ground from which problems are identified and will increase confidence in safety, reliability and mission success.

SUMMARY

The avionics development laboratory and the Lunar/Mars Initiative advanced development program will provide a comprehensive approach to the complex issues and problems in the development of an avionics system (Figure 14). The program will be applicable to all program elements and will provide operational validation of all external vehicle interfaces affecting the avionics system. Innovative approaches will be required to reduce program costs and still maintain a high degree of manned and unmanned safety. The multi-use laboratory will be adaptable to all program phases and will support both vehicle and program interfaces. The laboratory will support the increases in productivity necessary for the efficient conduct of the Lunar/Mars Initiative program.

UPPER STAGES

Space Transportation and Exploration Office

WELCOME

SPACE TRANSPORTATION AVIONICS
TECHNOLOGY SYMPOSIUM

Williamsburg, VA.
November 7 - 9 , 1989

SPACE TRANSFER VEHICLE AVIONICS ADVANCED DEVELOPMENT NEEDS

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PROGRAM DEVELOPMENT
SPACE TRANSPORTATION AND EXPLORATION OFFICE
UPPER STAGE GROUP

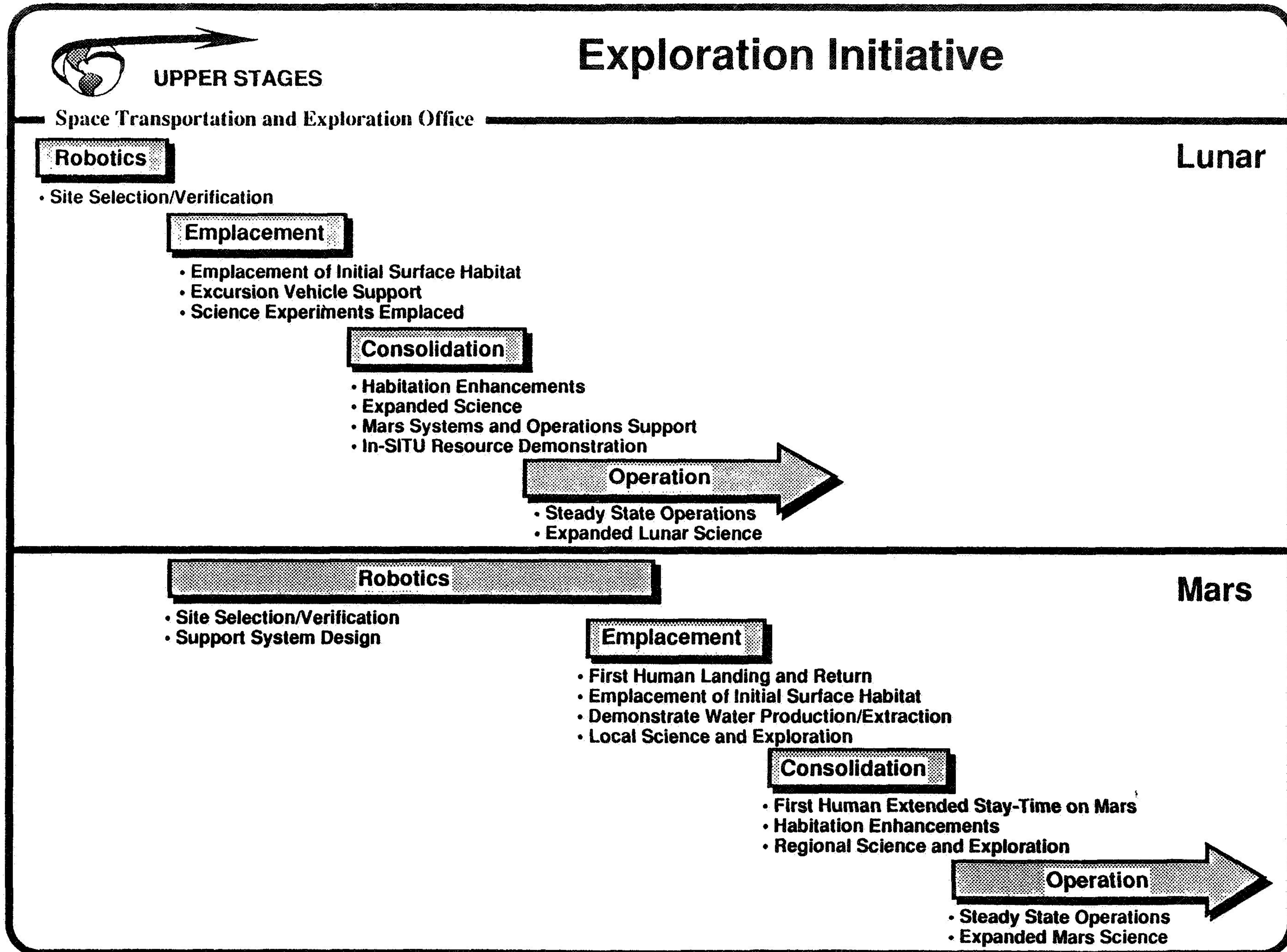
* Significant inputs provided by MSFC's STV Study Contractors

AGENDA

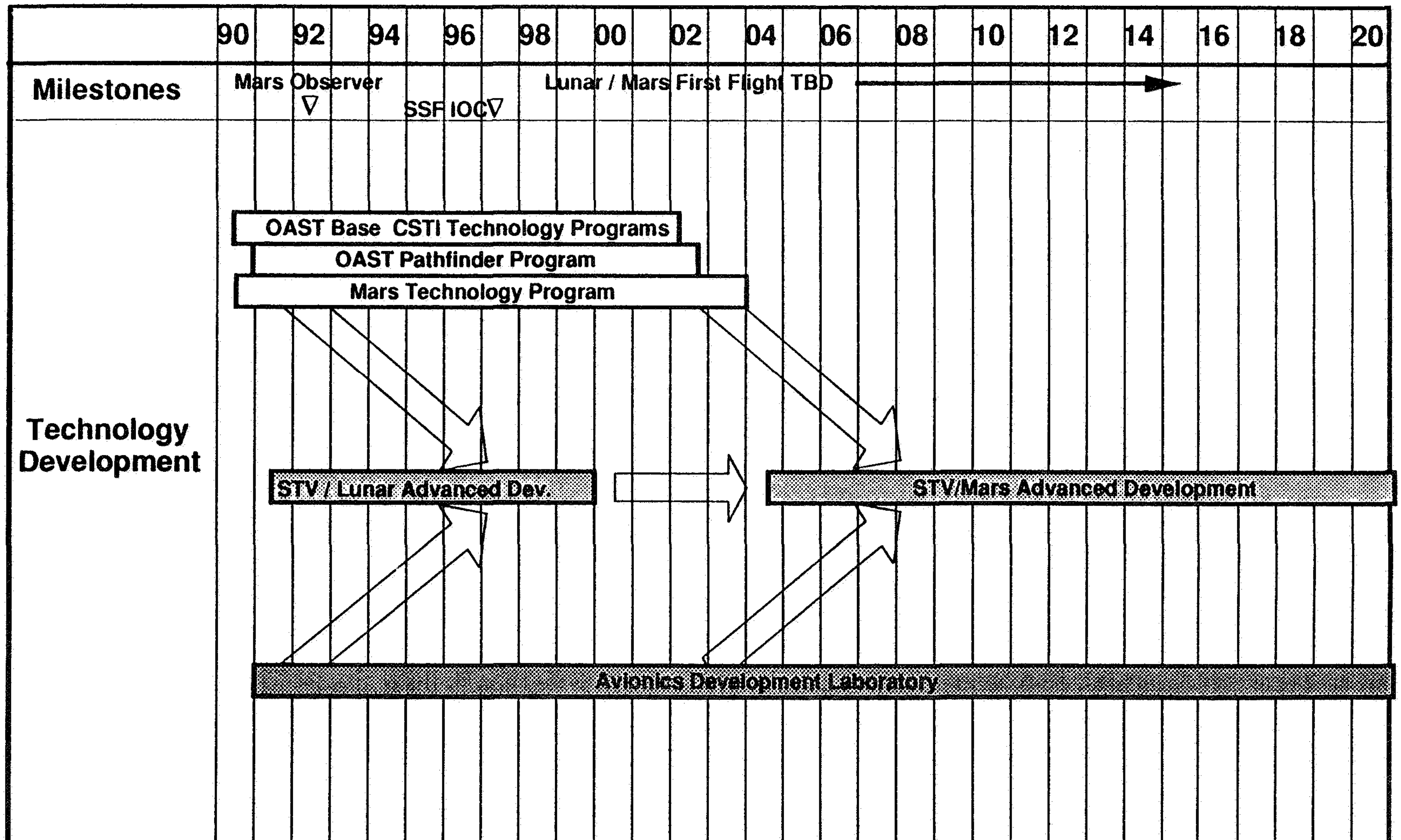
- PROJECT DESCRIPTION OVERVIEW
- AVONICS ADVANCED DEVELOPMENT CRITERIA / CONCEPT
- AVIONICS ADVANCED DEVELOPMENT NEEDS / EXAMPLES
- ADVANCED DEVELOPMENT DEMONSTRATIONS
- ADVANCED AVIONICS LABORATORY PHILOSOPHY / OVERVIEW
- BENEFITS OF AVIONICS ADVANCED DEVELOPMENT
- SUMMARY

Appendix 1 - Avionics Advanced Development Needs

Appendix 2 - Avionics Development Laboratory Support Phases


UPPER STAGES
Space Transportation and Exploration Office
Exploration Initiative
Lunar
Robotics
• Site Selection/Verification
Emplacement
• Emplacement of Initial Surface Habitat
• Excursion Vehicle Support
• Science Experiments Emplaced
Consolidation
• Habitation Enhancements
• Expanded Science
• Mars Systems and Operations Support
• In-SITU Resource Demonstration
Operation
• Steady State Operations
• Expanded Lunar Science
Mars
Robotics
• Site Selection/Verification
• Support System Design
Emplacement
• First Human Landing and Return
• Emplacement of Initial Surface Habitat
• Demonstrate Water Production/Extraction
• Local Science and Exploration
Consolidation
• First Human Extended Stay-Time on Mars
• Habitation Enhancements
• Regional Science and Exploration
Operation
• Steady State Operations
• Expanded Mars Science

LUNAR / MARS OUTPOSTS TECHNOLOGY / ADVANCED DEVELOPMENT



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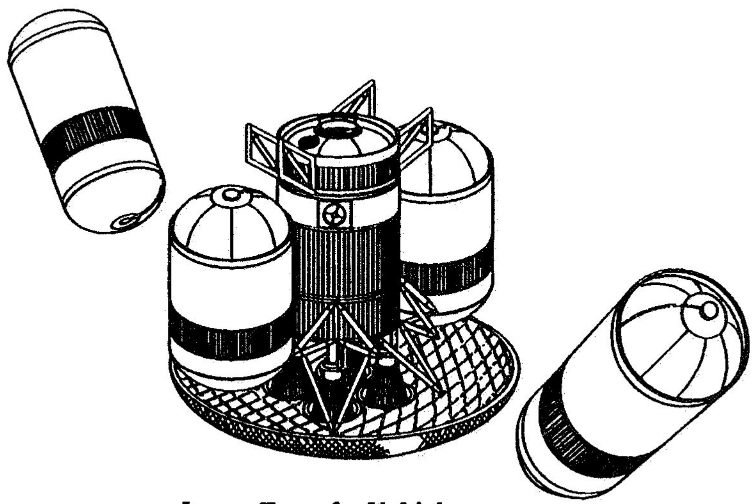
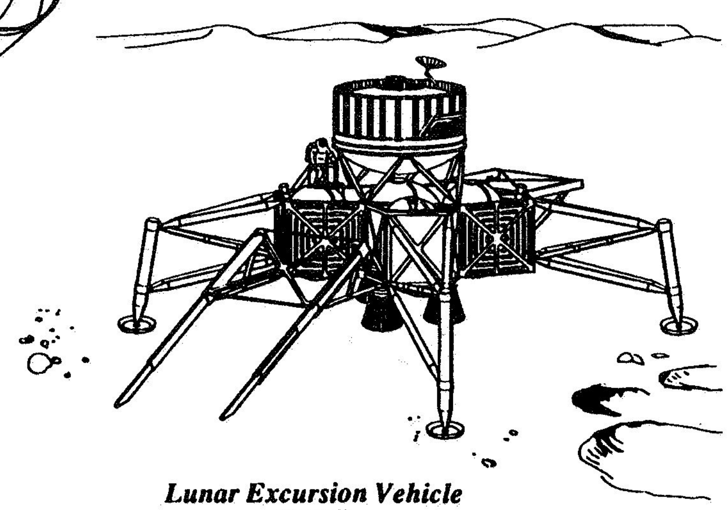
Typical Lunar Transportation System



Lunar Transfer Vehicle
(LTV)



Lunar Excursion Vehicle
(LEV)

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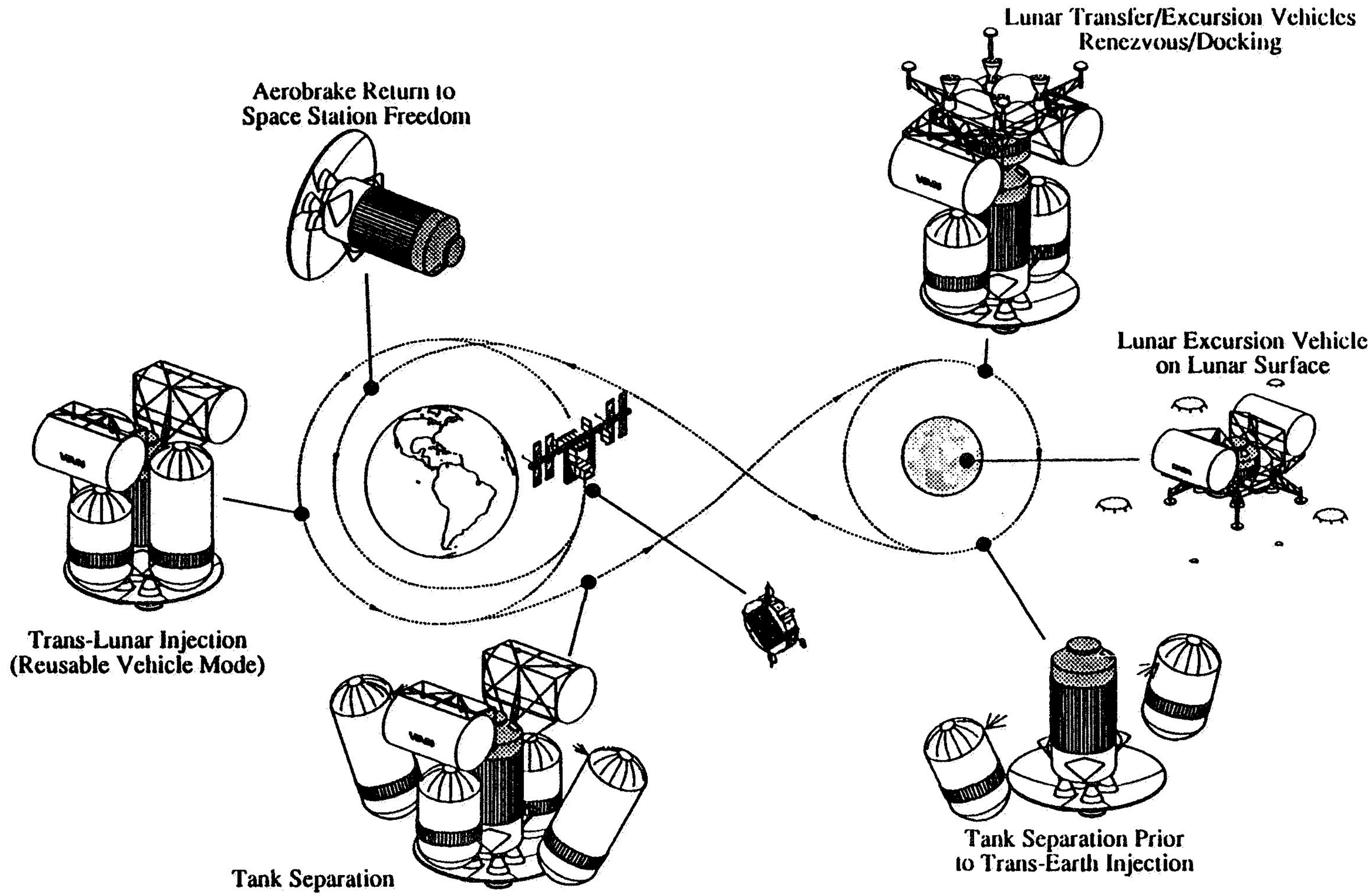
Lunar Transfer Operations



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Mars Transfer Operations

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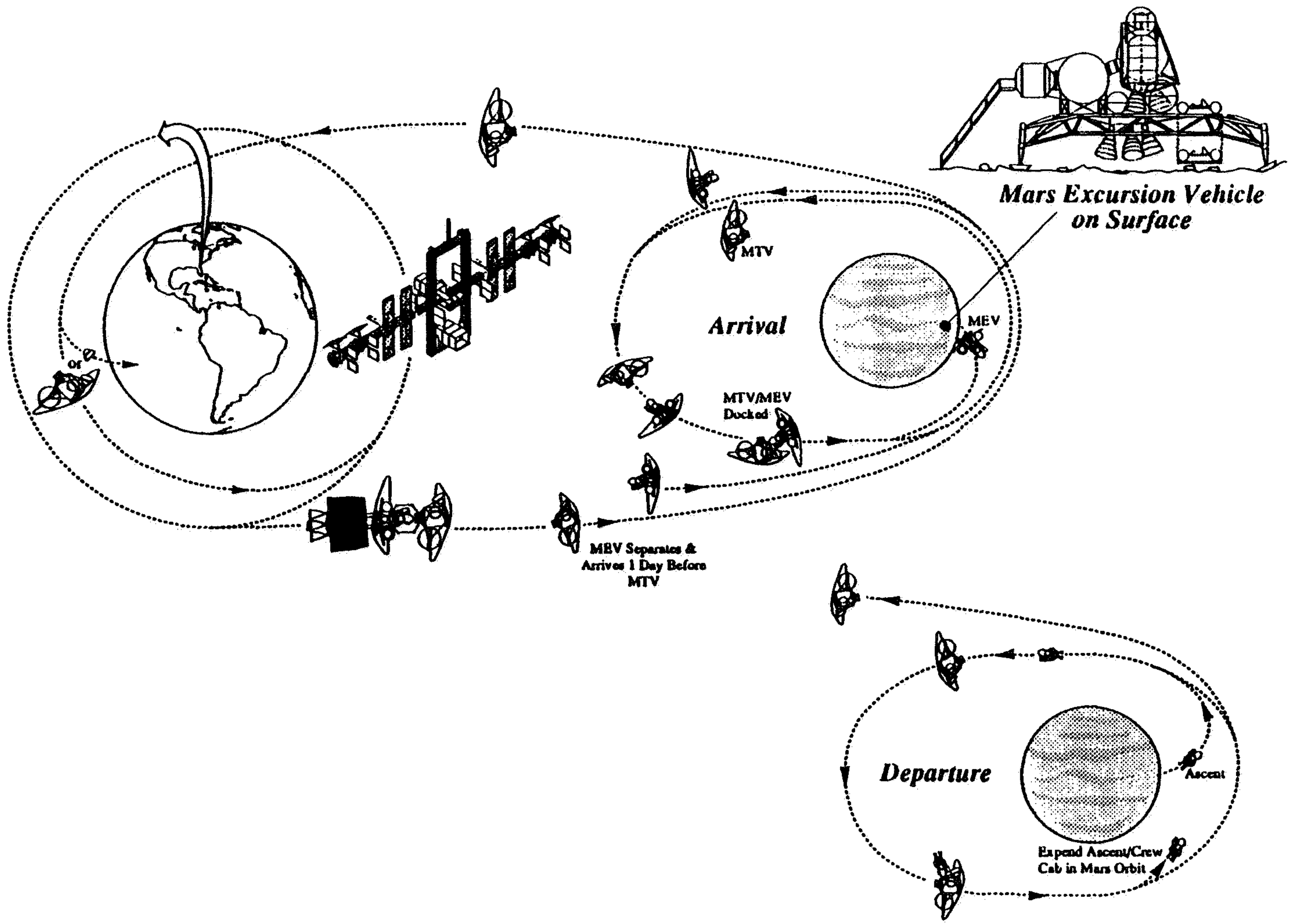

C-3

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Vehicle, Advanced Development & Technology

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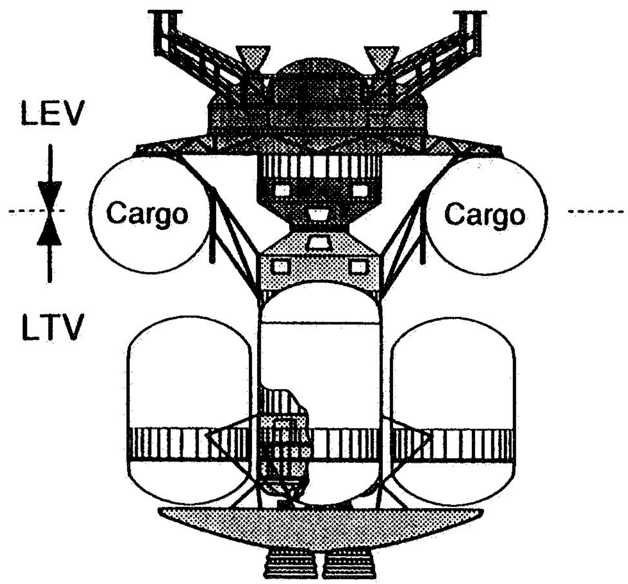
Vehicle



Advanced Development	Technology
• Space Transfer Vehicle Engine	●
• Advanced Cryo Storage and Transfer	●
• Cryo Auxiliary Propulsion	●
• Aerobrake	●
• Avionics	○
• Vehicle Structures	●
• Radiation Protection	
• ECLSS	
• Vehicle Assembly	●
• Vehicle Flight Ops.	

AVIONICS ADVANCED DEVELOPMENT CRITERIA / CONCEPT

CRITERIA

- Perform Technology / Advanced Development Efforts Where Necessary To:
  - Meet mission requirements
  - Make missions easier or less expensive to accomplish
  - Help reduce uncertainties or gain insight to confirm an approach
  - Discover problems and work out solutions in a lower-cost environment, prior to start of full-scale hardware development.

CONCEPT

- Technology and Advanced Development:
  - Provides hardware / concept demonstration
  - Supports early configuration / concept selection
  - Provides results available to support vehicle / program options at PDR, CDR and early operations phase
  - Provides operations validation
  - Provides performance validation
  - Provides cost validation
  - Provides common core avionics test bed for all vehicles
  - Managed within the project office
  - Implemented by government labs, prime contractors and subsystem / component contractors

AVIONICS ADVANCED DEVELOPMENT NEEDS

	LUNAR	MARS	OMV/ROBOTIC SERVICER
PERFORMANCE			
• Vehicle Avionics	X	X	X
• Vehicle Software	X	X	X
• Vehicle Health Management	X	X	X
• Autonomous Self Test & Checkout	X	X	X
OPERATIONS			
• Automated Vehicle Assembly	X	X	X
• Autonomous Rendezvous & Docking	X	X	
• Vehicle Flight Operations Simulations	X	X	X
• Autonomous Landing	X	X	

UPPER STAGES

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ADVANCED AVIONICS DEVELOPMENT NEEDS VS LABORATORY / DEMONSTRATION

AVIONICS SYSTEMS NEEDS	DEVEL/PHASE LABORATORY					DEVEL/PHASE FLIGHT DEMO				
	A	B	C	D	OPS	A	B	C	D	OPS
VEHICLE AVIONICS	X	X	X	X	X			X	X	
VEHICLE SOFTWARE	X	X	X	X	X				X	X
VEHICLE HEALTH MANAGEMENT			X	X	X				X	X
AUTONOMOUS SELF-TEST & CHECKOUT			X	X					X	X
AUTOMATED VEHICLE ASSEMBLY			X	X	X			X	X	X
AUTONOMOUS RENDEZVOUS & DOCKING		X	X	X				X	X	X
VEHICLE FLIGHT OPERATIONS SIMULATIONS			X	X					X	X
AUTONOMOUS LANDING		X	X	X				X	X	X

ADVANCED AVIONICS LABORATORY PHILOSOPHY

An advanced avionics laboratory for on-orbit transportation should have the following capabilities to :

- Evaluate concepts and technologies employed in vehicle design through extensive use of software tools.
- Conduct rapid prototyping (hardware and software) of concepts for evaluation.
- Conduct sub-system simulations to explore performance, e.g., dynamics, flight code validation, calibration, etc.
- Conduct end-to-end simulations containing a mixture of simulated, emulated and prototype avionics systems.
- Conduct integrated hardware-in-the-loop simulations for the purpose of validation and verification.
- Conduct real-time mission monitoring, analysis and mission support.

UPPER STAGES

ADVANCED AVIONICS LABORATORY OVERVIEW

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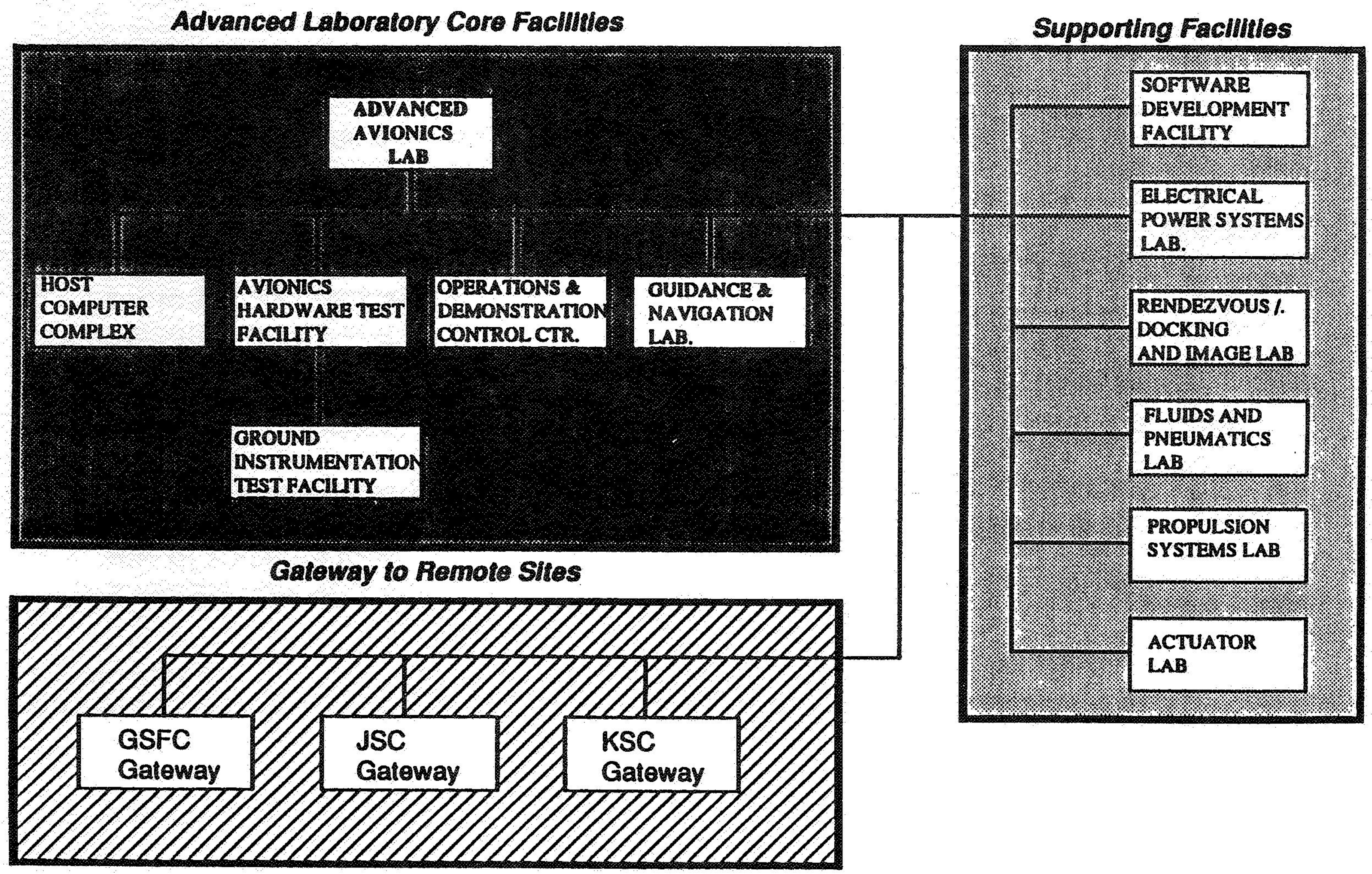

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PHASES OF AVIONICS SYSTEMS DESIGN SUPPORTED BY A LABORATORY

Phases A: Preliminary Analysis • Systems Analysis • Modeling and Simulation • Concept Development	**Phase B: Design Definition** • Refine Avionics Design Concept • Establish Performance Requirements • Define High Risk or New Technologies • Define Data Management System
Phase C/D: Design/Development • Specify Avionics System • Design Components • Design Operations • Qualify Components • Validate System • Verify System	**Phase E/F: Production/Operations** • Support Training • Support Ground Operations • Support Flight Operations • Preform Software Maintenance • Perform Hardware Maintenance

BENEFITS OF ADVANCED DEVELOPMENT / INTEGRATED AVIONICS LABORATORY

Advanced development:
- Validates design approaches
- Demonstrations provide solid points for design
- Enables confirmation of performance specilfications

Integrated Avionics Laboratory:
- Reduces development time, provides early resolution of design issues and problems
- Key overall systems design, development & operations tool
- Aids productivity - "doing it right the first time"
- Reduces program cost, schedule & technical risk

Value
- Timely demonstration data for cost effective decisions throughout the life of a program

Advantages / Payoffs
- "Common Ground" for design, development, test, manufacturing and operations
- Proof of concept
- Continuous and evolving support to all program phases as requirements and designs mature
- Reduced unforseen / unpredicted test problems and failures
- Increases confidence in safety, reliability and mission success

SUMMARY

- Operational Validation of External Vehicle Interfaces

- Provides Early Demonstration of Redundancy Management Concepts

- Philosophy Applicable for all Program Elements
  - Components & Subsystems
  - Systems Performance & Integration
  - Vehicle Performance & Integration

- Innovative Approach Required
  - Reduce Program Costs
  - Manned & Unmanned Safety Paramount

- Multi-use Laboratory:
  - All Vehicles - LTV, LEV, Crew Module
  - Intra- and Extra-vehicle & Program Interfaces
  - All Program Phases - Concepts, Design, Integration, Test, Validate

- Increase Required in Productivity
  - User Friendly Capabilities Designed-in
  - Demonstrate/Verify System Concepts in Phases A & B
  - Autonomous Mission Operations
  - Self Monitor-Test-Validation Mandatory

APPENDIX 1 - Avionics Advanced Development Needs (Quad Charts Descriptions)

VEHICLE AVIONICS (Fig 8A) - Vehicle avioncs is defined as the data management system (comprising the computers,data storage, bus architecture),electrical power distribution, navigation and flight control sensors/effectors, propulsion control, communications and tracking, environmental control, vehicle sensors and associated interfaces required to support the mission.Figure 8A defines the need for integrated avionics systems which must be developed for exploration vehicles. These systems require new technology and the technology application must be initiated early in the conceptual design program and evolved through the Lunar/M.ars flights. The design and development of design methodologies supports fault tolerant architectures with the use of expert systems and neural networks to improve system level reliability and resiliency.
Advanced software development, production and maintenance techniques are an integral part of the evolving system development, simulation, test and validation environment The benefits of lower cost operations, high reliability and confidence and flexible configurations, for testing and flight operations mandate an increase in avionics technology. New technology is mandatory for advanced methodologies, analysis and concepts within 2-3 years, followed by advanced simulation and testing one year later and operational testing beginning in 1995.

VEHICLE SOFTWARE (Fig.8B) - The vehicle software consists of the operating system,fault detection, isolation, and recovery algorithms, and all application software required to perform all mission operations.The integrated design and development of lunar vehicle software is key to meeting the cost, safety, reliability, and flexibilty requirements of these missions. This involves determining mission specific operating system requirements, and early identification of hardware/software interfaces.Prototype system development is followed by integration of the software operating system with breadboard hardware to evolve the avionics system. The system safety of both manned and unmanned operating modes must be determined and limitations understood. The new technology schedule will develop operating system requirements in 2 years, followed by design of the fault tolerant operating system the following year. The operating system will then be verified functionally on the hardware simulator after an additional two years of operating system integration with the hardware system.

VEHICLE HEALTH MANAGEMENT (VHM)Fig.8C) - VHM directs built-in-test (BIT) and diagnostic tests to support on-orbit assembly and integration. It also supports equipment reconfiguration due to faults and/or fault prediction during all operational phases. A major design feature will be integrated, indigenous, health monitoring on key vehicle systems. This avionics capability is the major key to space based transfer and excursion vehicle reuse with a minimum maintenance goal.This approach partitions component, subsystem and system level information, handles intermittent, time variant, and multiple faults, and provides trend analysis from the onboard vehicle sensor complement.This approach results in a level of redundancy management that is required for the evolutionary program which has not been achieved to this day.The goal is to provide "designed in", autonomous vehicle system integration and checkout, with significant reduction in today's required mission operations and human resources.The increased reliabilty, fault tolerance, system reconfiguration and flexibility will require additional onboard computer and software resources.The technology development schedule includes definition of computer resources within the next year, development of the simulation and stability scenarios the following year,vehicle monitoring system partition one year later, and system level demonstration of the fault reporting methodologies in 1995.

AUTONOMOUS SELF TEST AND CHECKOUT (Fig. 8D) - Autonomous self-test and checkout consists of BIT hardware and software that is utilized during all mission phases.BIT is typically executed during system startup and operates in the background during normal operations. The unmanned Lunar reflight checkout and ascent preparations without a crew present and minimum maintenance goal provide the most significant drivers for Lunar vehicle autonomous self test and checkout. This capability must be incorporated as an integral part of the vehicle concepts and designs. Similarly Freedom and any other future orbital nodes require minimum resource allocation for assembly, repair, servicing, mission to mission turnaround, and flight recertification.These support elements emphasize the need for autonomous reconfiguration with minimal work load on the flight crews. This technological advancement will reduce costs and increase reliability by reduction of multiple supporting hardware checkout units and their continuing operational usage; in the factory, at KSC, at Freedom and on the Lunar surface. Current tactical aircraft technology has progressed significantly in this application but only limited useage has been implemented in space vehicle applications.

VEHICLE ASSEMBLY (Fig.8E) Most candidate vehicle designs require on-orbit or node assembly for the initial stage reasssembly for reuse flights. Even in the minimum maintenance scenario, servicing, repair, replacing expended propellant tankage for reflight, recertification and payload integration will be required. These individual elements are large in size and /or mass, 45 ft. (xx m) dia. aerobrakes, and 4.3 x 30 m propellant tank assemblies with individual masses up to 48 t assembled to a 30m core. The building blocks are delivered to Freedom for man tended or telerobotic final assembly, test and flight certification. The goal is to minimize on-orbit time and crew resources requirements, minimize the number of earth to orbit flights in the recurring operations mode, and provide a simple and reliable assembly operation. The operational baseline uses the OMV as a tug around Freedom to transfer the major elements, and the telerobotic servicer and Freedom remote manipulators to locate, position, interface, and integrate the multiple elements. Fluid, gas, commodity, plumbing, electrical and, data interfaces are mated by the IVA crew controlling the servicer/manipulator and assembly fixtures, EVA is used only when essential or in contingencies. NDE inspection techniques and other related technologies such as avionics and software, automated test and checkout are combined to simplify the orbital timelines. A balance between cost and complexity is maintained with a focus on safety and successful mission completion for orbital and lunar surface applications. Current STS SPAR arm applications, AI based DRPA initiatives, (DITA), and NASA flight telerobotic servicer provide examples of the technology foundation for this effort.

AUTOMATED RENDEZVOUS AND DOCKING (Fig. 8F), The Lunar/Mars missions share the requirement for automated rendezvous, closure, docking, and mating in low earth orbit, lunar and planetary orbits for unmanned missions. The resultant systems must also provide for primary on-board crew control using the same systems with appropriate man-machine interfaces. The technology requirements include mission techniques, GN&C algorithms, appropriate ranging parameters, sensors, crew display and control, and automated power, control, and consummable disconnects for transfer and interfacing between vehicles. Technology requirements are also derived from the mandatory crew display, control and command interfaces. The major drivers include the remote unloading, transport and proximity operations of unmanned ETO deliveries and transport to Freedom, and the LLO rendezvous operations involving combinations of manned and unmanned lunar transport and excursion vehicles. The key benefits include precision control systems for terminal docking and mechanical,and electrical systems integration. The major tasks include operations analyses, determination of safety technologies

and sensor candidates, design of reusable quick disconnects, and the design of alignment and terminal latching devices. The current technology base for manned and unmanned vehicles includes demonstrated techniques and hardware from Gemini, Apollo, Skylab, and Shuttle with emerging technology from Freedom, OMV, Pathfinder and CSTI which provide proximity, ranging, guidance algorithms and basic AI technology.

VEHICLE FLIGHT OPERATIONS (Fig. 8G) The long duration Lunar missions present new challenges in operating complex, multiple vehicle and planetary surface stations which challenge the command, control, communication and human flight control resources. Increased lunar mission vehicle autonomy is needed for potential six month low lunar orbit transfer missions, with onboard management information processing, storage and manipulation of data for normal and contingency mission operations. The command role in individual vehicle operations will be with each vehicle while the flight control team on the ground, at station, or on the lunar surface are in support mode. The major drivers in the expanding operations technologies are the very high costs per flight due to personnel -intensive mission reconfiguration software, changing mission planning documentation, simultaneous operations of several flight elements, and multiple round the clock mission support teams. Mars missions will extend flight durations from months to years and will tend to increase operational costs exponentially.

AUTONOMOUS LANDING (Fig. 8H) Both Lunar and Mars unmanned excursion vehicles and surface hoopers will require autonomous onboard landing control and site selection. Closed loop terminal descent control form hover to touchdown is required. Communication time delays from the moon or Mars to earth make it impractical to attempt remote control of the final landing sequence. For manned missions, a safe override of the autonomous system must be provided. Autonomous landing is required for early cargo delivery and mission contingencies.

VEHICLE AVIONICS

DESCRIPTION

- Define, Develop, & Demonstrate Highly Fault Tolerant Avionics Architectures Capable of Automating Real-Time Mission & Vehicle Management Functions
- Provide Advanced S/W Development System
- Develop & Demonstrate Advanced Vehicle Subsystem Monitoring Capability For All Phases of Mission

MAJOR DRIVERS/BENEFITS

- Enabling Capability For Space Based Vehicles
- Redline Determination Increases Reliability & Probability Of Mission Success
- Reduces Turn-Around Time
- Reduces Dependence on SSF
- Reduces Software Maintenance Costs

MAJOR TASKS

- Determine Integrated System Requirements Including Data Thru-put
- Coordinate With & Incorporate Aerobrake GN&C Development Efforts
- Test & Demonstrate Key Components & Subsystems
- Simulations & Ground Testing of Integrated Systems

CURRENT TECHNOLOGY

- IUS & Centaur Basis - Ground Based Systems
- SOTA Has Neither Required Level Of Internal Reliability Nor Fault Isolation Capability
- Inflexible To Modifications & Requires Intensive Manpower For Flight Validation
- CSTI (Autonomous Systems) & Pathfinder (Autonomous Rendezvous & Docking) Provide Basic R&D in Expert Systems and Related AI Development

VEHICLE SOFTWARE

DESCRIPTION

- Provide Avionics Hardware Operating System
  - Deterministic
  - Validatable
- Support Development, Integration & Execution Of Software Algorithms
- Software Must Design-In Hardware Observability and Control

MAJOR DRIVERS/BENEFITS

- Safety - Vehicle, Mission, Crew
- Reduce Software Development Risk
- Support Self-Test & Checkout
- Increase System Reliability
- Demonstrate & Validate Hardware Testability

MAJOR TASKS

- Determine Mission Operational Requirements
- Classify Hardware/Software Interfaces
- Develop Prototypes For Avionics Lab Hardware
- Develop/Integrate Operating Systems With Breadboard Hardware
- Proof Of Concepts

CURRENT TECHNOLOGY

- Embedded Systems Use Ad Hoc Real-Time Executive (Even With ADA & CASE Tools)
- Hardware/Software Integration Is An Afterthought
- Only Door to Moderate Visibility of Hardware From Software

VEHICLE HEALTH MANAGEMENT

DESCRIPTION

- Diagnose / Handle All Faults
  Intermittent, Time Varying, Multiple
- Provide Redundancy Management Through Dynamic Reconfiguration
- System/Subsystem/Component Partitioning
- Health System Reconfiguration

MAJOR DRIVERS/BENEFITS

- Usage of Onboard Computer Resources
- Reduced Mission Operations & Costs
- Reliable, Reconfigurable & Fault Tolerant System
- Autonomous Integration & Checkout

MAJOR TASKS

- Identify Computer Resources/Requirements
- Develop Simulation / Testability Scenarios
- Develop/Verify VHM System Partitioning
- Develop Fault Reporting Methodologies

CURRENT TECHNOLOGY

- VHM Added On, Not Designed In
- Primitive Or No Long-Mission Real-Time Fault Recovery

AUTONOMOUS SELF TEST & CHECKOUT

DESCRIPTION
- High Coverage Built-In Self Test
- Autonomous Integration C/O
- Vehicle Sensors & Health Monitoring
- Autonomous Redundancy Management
- Predictions of Impending Failures

MAJOR DRIVERS/BENEFITS
- Low Cost Assembly/Mating/Ops At SSF
- Limited Resources For Repair During Mission
- Minimal Orbital Node Support Services
- Safe & Predictable Reconfiguration Behavior
- Predict Impending Failures - Crew Safety

MAJOR TASKS
- Integrate Requirements With VHM and Automated Assembly Technologies
- Develop Methodology For Predicting
- Develop Methodology & Database Methods For Measuring/Storing Performance Trend Data
- Standardization Of Mech./Elec. Interfaces (Vehicle & With SSF, OMV & Telerobotic Servicer)
- Paperless Procedures

CURRENT TECHNOLOGY
SOTA Is Limited

- ALS Paperless System "Goal"
- Aircraft Technologies
- Few Relevant Applications

VEHICLE ASSEMBLY

DESCRIPTION

- Develop Techniques and Components For Automated Assembly And Checkout
- Focus Generic I/F Technologies to Lunar Mission Applications
  - Vehicle Assembly
  - Aerobrake Assembly/Inspection/Test
  - Propellant Transfer
  - Crew Module Refurb, Installation & Verification
  - Vehicle/Payload On-orbit Integration

MAJOR DRIVERS/BENEFITS

- Massive Elements, Many Missions
- Complex Interfaces

- Minimize EVA and SSF Crew Impact
- Simplify On-Orbit Operations
- Reduction in ETO Traffic

MAJOR TASKS

- Design Standardization
  - Docking/Grappling Mechanisms
  - Vehicle Element Interfaces
- Define I/F Verification & Checkout Methods
- Quality Inspection Techniques & Procedures
- Devise Basic Operational Techniques
  - Manned Control
  - Manned Supervision
  - Autonomous
- Control System Implementation
- Flat Floor Simulations & Tests

CURRENT TECHNOLOGY

- None For Manned Systems

AUTOMATED RENDEZVOUS, DOCKING AND MATING

DESCRIPTION

Develop Capability to Rendezvous, Dock, & Mate Payloads in Low Earth And Lunar Orbits

- Develop Mission Techniques & Hardware
- Develop GN&C Algorithms
- Develop Range & Range Rate Sensors
- Demonstrate Automated Rendezvous & Docking in Flat Floor Simulations

MAJOR DRIVERS/BENEFITS

- Unloading of Unmanned ETO Transports
- Transport Payloads To LEO Node & Assemble
- LTV/LEV Operations in LLO

- Fine Control of Terminal Docking
- Electrical & Fluid Integration

- Minimize Node Support Services
- Increased Safety, Reliability, & Efficiency
- Reduced Cost & Human Risk

MAJOR TASKS

- Operations Analyses
- Hazard & Safety Analyses
- Focus Generic Technologies To Lunar Initiative Needs
- GN&C Development
- Sensor Definition
- Electrical & Fluid Service Connectors
- Latches, Utilities, Docking Structure
- Electronic Simulations
- Scaled Floor Simulations
- On-Orbit Demonstrations (OMV/SSF Testbed)

CURRENT TECHNOLOGY

- Active Piloted Vehicles (Skylab/CSM, ASTP)
- Teleoperation/Robotics (STS/SPAS)
- SSF Experience Base in AI Techniques
- OMV Develops Autonomous Rendezvous
- Pathfinder To Develop Generic Components
  - Proximity Radars & Laser RangeFinders
  - GN&C Algorithms
  - Docking Mechanisms
- CSTI Developing Basic AI Technology

VEHICLE FLIGHT OPERATIONS

DESCRIPTION

- Advanced Missions Involve Unique, Complex And Lengthy Mission Scenarios
- New Levels of Vehicle Autonomy Required To Achieve Required Safety, Survivability, & Cost
- On-Board Management, Manipulation, & Storage of Huge Data Quantities

MAJOR DRIVERS/BENEFITS

- Enabling Capability For Mars Missions
- Comm Occultation on Lunar Backside
- Simultaneous Operations of Several Major System Flight Elements
- Many Missions - Flight Times In Months/Years
- Complex Maneuvering & Control Requirements
- Reduced Costs for Mission Planning, Flight & Ground Crew Training, & Ops Support

MAJOR TASKS

- Analyses of Ops Requirements
  - LEO Build-up & Departure
  - Lunar Orbit, Landing, Take-off
  - Lunar Surface Activities
  - Return to LEO, Aerobrake, &SSF Recovery
- Develop New Ops Methodologies & Levels of Autonomy Required For Mission Phases
- Software Development & Test

CURRENT TECHNOLOGY

- SOTA is Manpower Intensive Mission & Payload Operations - Ground Based
  - Extensive Training & Rehearsals
  - Data Interpretation By Ground Crews

AUTONOMOUS LANDING

DESCRIPTION

- Safe Autonomous Landing At A Site In A Preselected Area
  - Terrain Recognition / Avoidance
    Slopes, Crevasses, Boulders
  - Propellant & Timeline Management
- Safe Override For Manned Missions

MAJOR DRIVERS/BENEFITS

- Required For Early Cargo Delivery
- Communication Time Delays
- GN & C and Vehicle Response
- Safety - Abort to Orbit

MAJOR TASKS

- Similarity Of Manned & Cargo Versions
- Sensor Technology, Selection & Development
- Adaptability To Emerging GN & C Algorithms
- Conceptual Simulations
  - Terrain Recognition & Anomalies
  - Propellant Slosh / Vehicle Dynamics
  - Impact System Dynamics

CURRENT TECHNOLOGY

- None Directly Related
- Aerodynamic / Earth Surface Systems
  - STS Landing System
  - Autonomous Land Vehicle Developing Related AI
  - Automated Landing For Commercial Aircraft
    Established Runways & Flight Paths

APPENDIX 2 - Avionics Development Laboratory Support Phases

Life Cycle Example:(Design Phases A & B)

The phase A/B of the LTV and LEV avionics system designs are critically sensitive to; the robustness of the design, the definition of system/subsystem interfaces and to the overall definition of requirements. One of the keys to overall enhancement of the engineering productivity during this phase is the ability to build system and subsystem models that are accurate representations with the capability to accommodate expected performance dispersions. This is important to reduce design cost and program risks, because of the increasing desire to accommodate changes in lunar mission requirements and provide future operational flexibility and robustness. Figure 12 A illustrates the relationships, tasks and data flows of the preliminary design phase.

In this laboratory concept, workstations are used to develop technical databases consisting of: system simulations, flight computer code, flight computer requirements, procurement specifications, and analytical test tools. This activity uses both Computer Aided Engineering (CAE) and Computer Aided Software Engineering (CASE) tools to develop advanced early prototype lunar vehicle design concepts. The early development of a prototype design concept facilitates the validating of the individual and combined system requirements. The form of early prototyping should be close, but not identical to, the actual targeted flight system with high resolution models used to complete any desired system simulation. The advantages of this approach is to; develop early interfacing and timing requirements for the lunar flight systems; develop, code and test design tools; enhance the interface between G&NC designers and flight software design and initiate manned crew interfaces in the overall concepts.

Figure 11 illustrates the interfaces between the laboratory and other program elements. The development of a distributed relational database is necessary to support the early system design phase. The inputs consist of: structural data such as a Nastran model, a solids model that provides elemental data for multi-body simulations and animations, the mission profile defining the time line and guidance parameters, and propulsion system models. The output from the laboratory consists of the performance estimate and interface control. The performance estimate gives dynamic animation results from the system simulations relating to the mission profile. More detailed results such as RCS specific impulse / performance profiles and TVC actuator power usage can also be derived. This level of performance data provides subsystem designers the parameters necessary for component design and analysis. The attributes of an early detailed design can be summarized as follows;

i.) The concurrent design of the subsystem requirements

critical to the operation of the avionics system.
ii) Early validation of mission performance in the context of robust design requirements.
iii) Early validation of procurement specifications critical to subcontract control.

Given adequate avionics research and development, this approach to design will allow faster more efficient preliminary design with significantly fewer design alterations downstream.

Avionics Preliminary Design (Phase A/B)
The first step in supporting the detailed design phase of the LTV and LEV is the hosting of a replica of the avionics systems including models of subsystem components and flight computers. The resultant simulation can be run real time to verify the flight software design and redundant architectures before any hardware is integrated into the loop. The interfaces shown in Figure 12 A/B Advanced Laboratories utilization summary by program phase connect workstations through specialized I/O boards designed to meet a typical flight bus standard.

Avionics Detailed Design: Distributed Processing (Phase C)
The second step, illustrated in Figure 12 C/D, is to replace the distributed simulations with subsystem hardware. At this stage there are two types of hardware interfaces: remote laboratory interface such as the Propulsion Laboratory, and lunar vehicle avionics subsystem interfaces such as the Inertial Measurement Unit. Interfaces with remote laboratories will be required to detail requirements such as data acquisition. A special case may be the Rendezvous and Docking Laboratory where the real-time dynamics of LTV docking with Freedom and LTV/LEV rendezvous and docking in LLO can be studied to the point of validating the LTV and LEV GN&C designs. The IMU is an interesting example in that the six-dof motion can only be partially imposed on the hardware via the rate table. It is necessary to inject the six-dof data stream into the IMU processor at rates that can exceed 1000Hz, hence the additional link between the IMU (processor) and the simulation workstation. This type of interface is necessary to enable validation and verification of the IMU software. The actuation subsystem is another interesting case. Although the actuation subsystem will be identical to flight hardware, it cannot be considered representative for closed loop simulations simply because it is not coupled with the rocket engine. A simulation of the actuator response coupled to the main engine will still be required as part of the workstation simulation running in parallel . to test the power bus integration.

It is important to note that the communication bus will become a replica of the LTV/LEV avionics buses. This is desirable if the

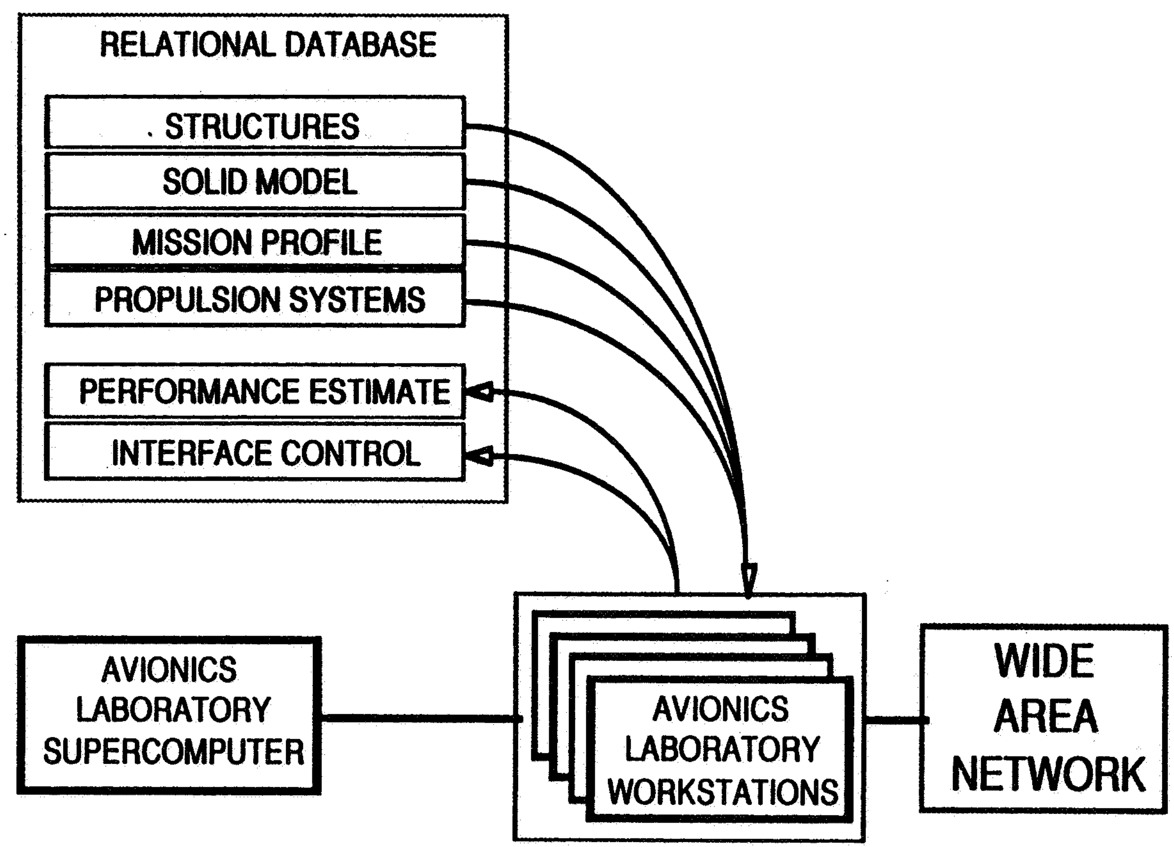
Propulsion Laboratory interface is viewed as the Propulsion Data Acquisition Unit, and the Rendezvous and Docking Laboratory is viewed as a proximity sensor. The subsystem bus interface is integral with the subsystem itself, so sensor simulation can be transparently replaced by the IMU.

Avionics Detailed Design: Hardware in the Loop (Phase D/E)
The third and final step, illustrated in Figure 12 E/F, is to complete the laboratory development for Flight Software Validation, Verification and mission support. The major additions to the laboratory include: complete subsystem integration, relocate the simulation into a flight system processor (the Data Acquisition Test and Simulation Unit - DATSU), interface test and ground support workstations, and interface the operations support system linked to other NASA center facilities. A specialized DMA monitor is included for Flight Code verification. One of the attributes of this Flight System architecture should be its ability to preform self-test. A complete end-to-end simulation can be performed to validate performance in any situation that could include environmental tests or even tests in orbit. Because the Flight System is cloned in the Avionics Laboratory, the results can be validated by comparison. To complete the test requirements, the Test Support Workstation is included for subsystem control and data acquisition. For example, because RCS solenoids have a limited life cycle, it is often necessary to isolate them during phasing tests. The Test Support Workstation controls the isolation and monitors the thruster signals. There are multiple trades which can be performed concerning functional allocation between the Test Support Workstation and the DATSU. With the growing emphasis on built-in-test, many of these test functions can be allocated to the DATSU.

Detailed Design: Flight Software Validation & Verification
One of the attributes of the Lunar Flight Systems architecture should be its ability to perform self-test. A complete end-to-end simulation as shown in Figure 12 G/H, Avionics Validation / Verification, can be performed to validate performance in any situation that could include environmental tests or even tests in orbit. Because the Flight System is cloned in the Avionics Laboratory, the results can be validated by comparison. To complete the test requirements, the Test Support Workstation is included for subsystem control and data acquisition. For example, because RCS solenoids have a limited life cycle, it is often necessary to isolate them during phasing tests. The Test Support Workstation controls the isolation and monitors the thruster signals. There are trades to be performed concerning functional allocation between the Test Support Workstation and the DATSU, with the growing emphasis on built-in-test, many of these test functions can be allocated to the DATSU.

As an example of the flexibility of the proposed Lunar avionics laboratory distributed system outlined in this paper, the following reconfiguration could be accomplished. The Avionics Simulation Workstation used during the design phase, could become the Ground Support Workstation. Using this workstation, data is extracted from the 'Relational Database' and the Mission Data Load computed (autopilot gains etc.). This data is combined with the mission flight software to form the software loads for the LTV and LEV which is then tested real time by the LTV/LEV Flight Systems. The Ground Support Workstation maintains the 'Performance Estimate' using both test data and the hypothesized telemetry data stream from the Flight System. Because the telemetry data set can be substituted for real time mission data, the Ground Support Workstation can support mission operations without modification. The Lunar operations example illustrates how systems integration of the avionics disciplines can yield increased productivity. The success this proposed system approach is predicated in part upon the development of fast workstations and flight computers, user friendly software and modern guidance and control methodologies. The "womb to tomb concept for the Lunar vehicle systems starts with concept definition and continues uninterrupted through sustained Lunar mission support for both manned and unmanned missions.

AVIONICS PRELIMINARY DESIGN



UPPER STAGES

Space Transportation and Exploration Office

AVIONICS PRELIMINARY DESIGN

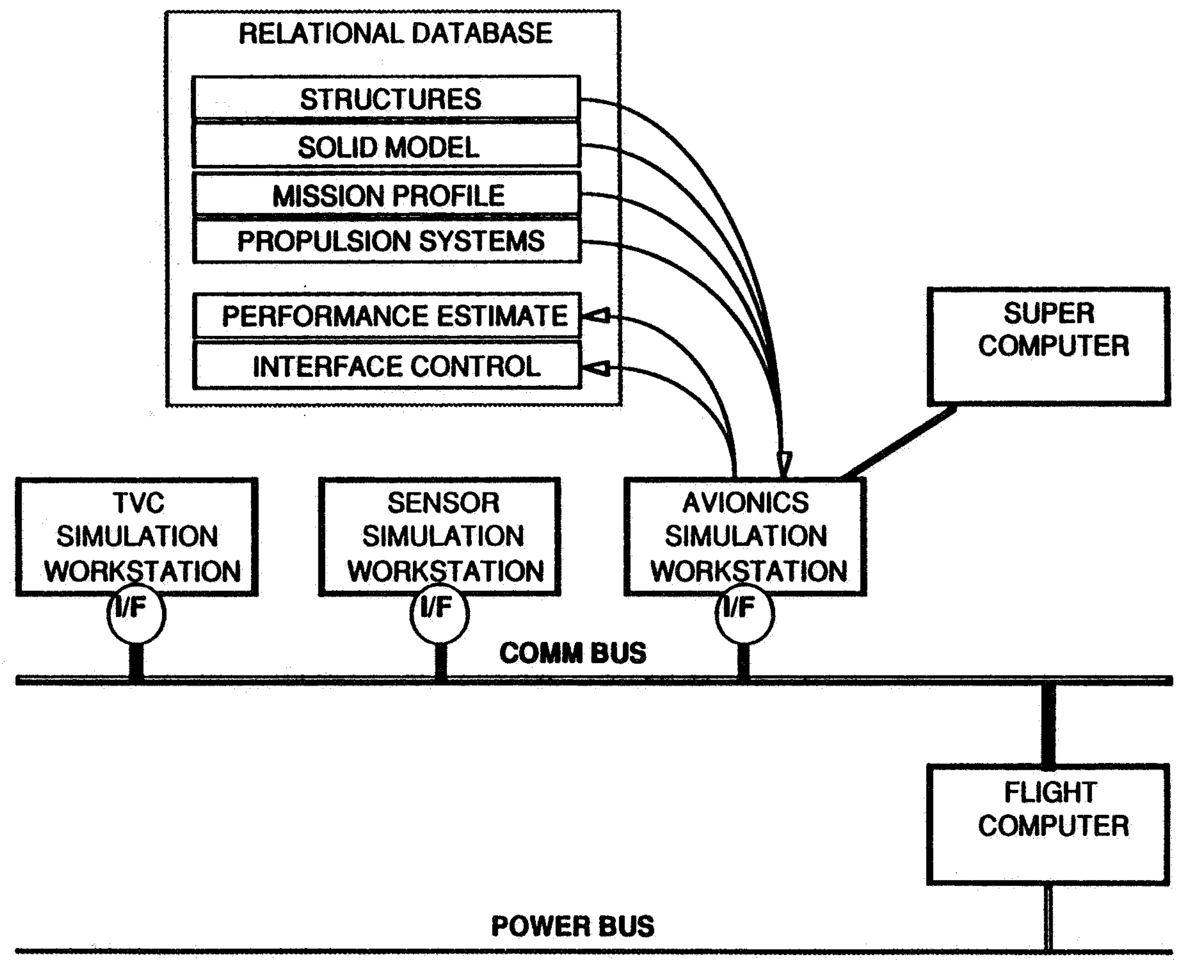
- CONCURRENT DESIGN
  - SYSTEM AND SUBSYSTEM INTERFACES MUST BE DEFINED EARLY IN THE PROGRAM IN ORDER TO ENSURE ALL REQUIREMENTS ARE ESTABLISHED
  - A RELATIONAL DATABASE COMMON TO ALL ELEMENTS OF THE PROGRAM IS REQUIRED TO ENSURE DATA PRECISION
  - EARLY DEFINITION OF AVIONICS PERFORMANCE RELATIVE TO MISSION REQUIREMENTS WILL CLARIFY SYSTEM AND SUBSYSTEM REQUIREMENTS. THIS WILL FACILITATE A ROBUST AVIONICS DESIGN

- PERFORMANCE VALIDATION
  - ACCURATE SYSTEM AND SUBSYSTEM MODELS ARE DEVELOPED TO FACILITATE GN&C DEVELOPMENT AND TEST
  - ACCURATE PERFORMANCE ANALYSIS IS ESSENTIAL TO ENSURE PERFORMANCE REQUIREMENTS WILL BE MET (ROBUST DESIGN)
  - EARLY PERFORMANCE VALIDATION IS REQUIRED TO ENSURE ACCURATE SUBCONTRACTOR REQUIREMENTS ARE ESTABLISHED

UPPER STAGES

Space Transportation and Exploration Office

AVIONICS DETAILED DESIGN



AVIONICS DETAILED DESIGN

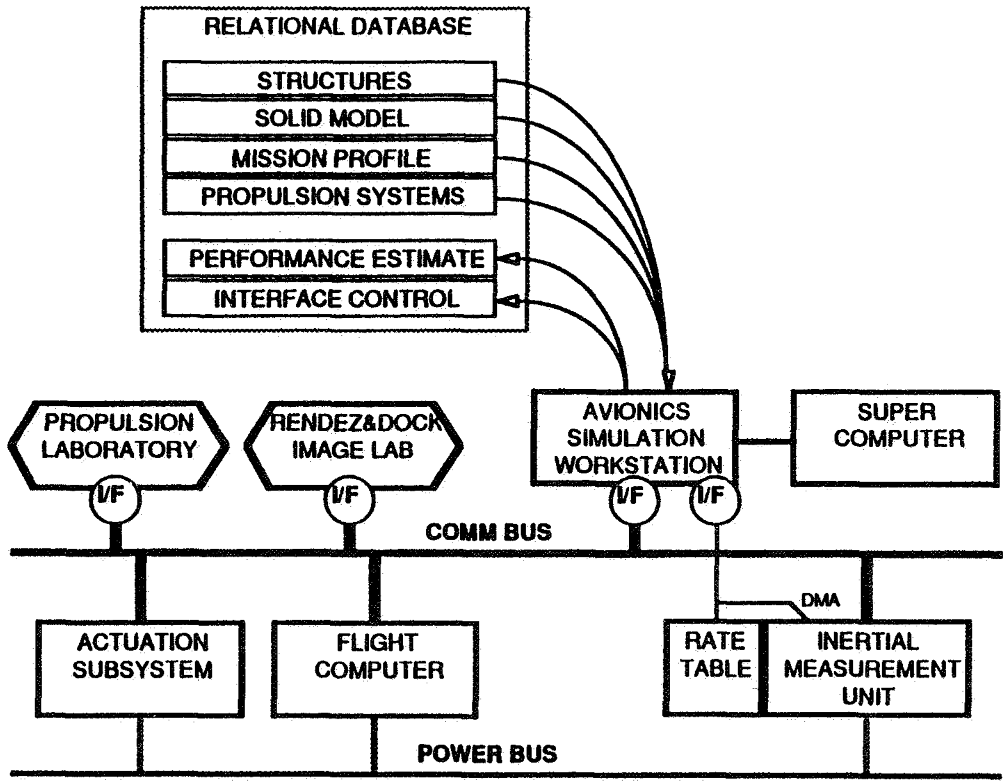
- AVIONICS SYSTEM FLIGHT ARCHITECTURE
  - THE FLIGHT COMPUTER, COMMUNICATIONS BUS AND POWER BUS ARE DEVELOPED AS THE FLIGHT SYSTEM BACKBONE
  - THE SUBSYSTEM MODELS ARE INTEGRATED INTO THE COMMUNICATIONS BUS TO VALIDATE SUBSYSTEM INTERFACES
  - THE GN&C CODE IS REHOSTED TO THE FLIGHT COMPUTER

- AVIONICS SYSTEM REAL-TIME PERFORMANCE
  - REAL-TIME PERFORMANCE IS VALIDATED DURING THE DETAILED DESIGN PHASE. THIS INCLUDES:
    - REDUNDANCY PERFORMANCE
    - SUBSYSTEM REDUNDANCY
    - BIT REQUIREMENTS
  - HARDWARE REQUIREMENTS ARE VALIDATED EARLY IN THE PROGRAM
  - MARGINS OF SAFETY ARE ESTABLISHED EARLY

UPPER STAGES

Space Transportation and Exploration Office

AVIONICS DESIGN: HARDWARE-IN-LOOP



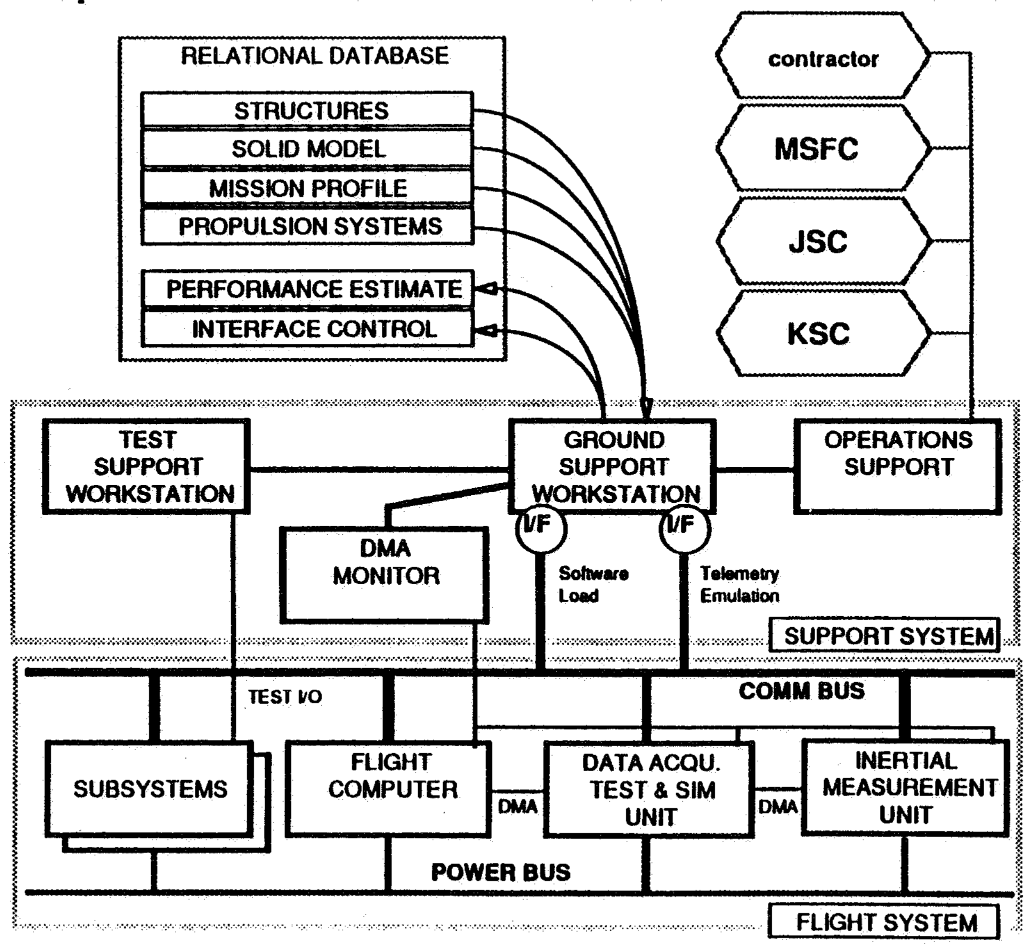
12E

AVIONICS DESIGN: HARDWARE-IN-LOOP

- INTEGRATION OF HARDWARE INTO THE REAL-TIME SIMULATION
  - SUBSYSTEM SIMULATIONS ARE REPLACED TRANSPARENTLY BY THEIR HARDWARE / SOFTWARE EQUIVALENTS
  - SUBSYSTEM PERFORMANCE IS TESTED IN A REAL-TIME ENVIRONMENT TO ENSURE ALL REQUIREMENTS ARE MET
  - THE REAL WORLD IS SIMULATED TO CLOSE THE LOOP THROUGH THE INERTIAL MEASUREMENT UNIT

- INTEGRATION OF REMOTE LABS INTO THE REAL-TIME SIMULATION
  - A REAL-TIME ENVIRONMENT IS PROVIDED TO MEET MORE SOPHISTICATED REQUIREMENTS
  - REMOTED LABS CAN BE INTEGRATED IN AN IDENTICAL FASHION TO REAL LIFE

AVIONICS VALIDATION & VERIFICATION



AVIONICS VALIDATION & VERIFICATION

- REPLICATE THE AVIONICS FLIGHT SYSTEM
  - DEVELOP THE FLIGHT SOFTWARE LOAD ON THE GROUND SUPPORT WORKSTATION
  - INTEGRATE THE REAL WORLD SIMULATION INTO THE FLIGHT SYSTEM TO PROVIDE A COMPLETE SELF-CHECK CAPABILITY USING DIRECT MEMORY ACCESS (DMA)
  - INTEGRATE A DMA MONITOR TO VERIFY THE SOFTWARE LOAD PERFORMANCE
  - INTEGRATE A TEST SUPPORT STATION FOR HARDWARE CHECKOUT

- OPERATIONS SUPPORT
  - INTEGRATE THE GROUND SUPPORT WORKSTATION INTO OPERATIONS SUPPORT
  - USE THE SELF-CHECK RESULTS FOR PRE-FLIGHT VALIDATION
  - USE THE REPLICA FOR IN-FLIGHT SUPPORT AND TELEMETRY COMPARISON
  - USE THE REPLICA FOR POST-FLIGHT ANALYSIS

714

S30458
18P
PRESENTATION 1.7

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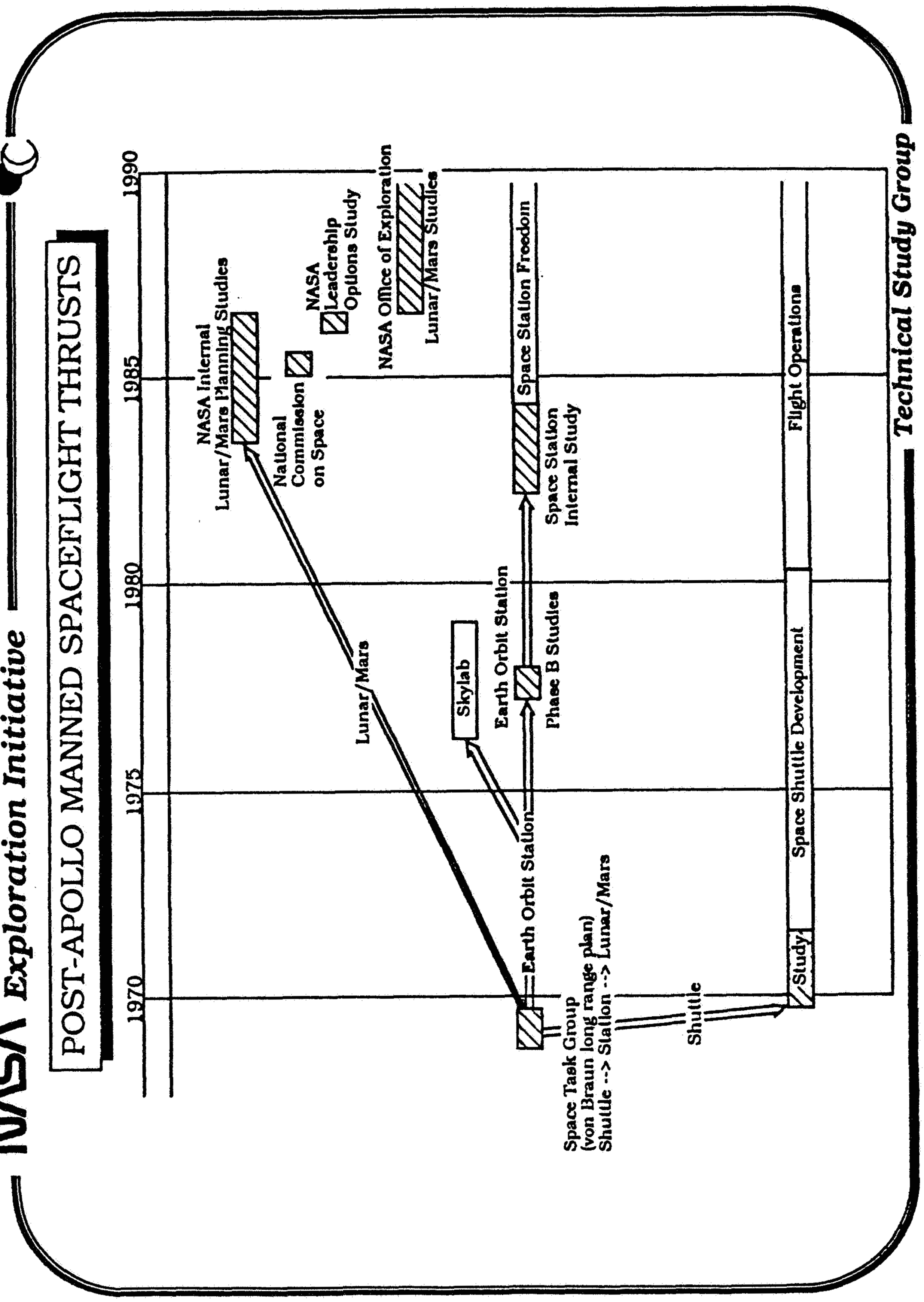
EXPLORATION INITIATIVES



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PRESIDENT BUSH
JULY 20, 1989

THE GOAL: "... TO ESTABLISH THE UNITED STATES AS THE PREEMINENT SPACE FARING NATION."

THE COMMITMENT: "... A SUSTAINED PROGRAM OF MANNED EXPLORATION OF THE SOLAR SYSTEM ... AND THE PERMANENT SETTLEMENT OF SPACE."

THE PLAN: "FIRST ... FOR THE 1990'S ... SPACE STATION FREEDOM ..

AND NEXT - FOR THE NEW CENTURY - BACK TO THE MOON.
AND THIS TIME BACK TO STAY.

AND THEN - A JOURNEY TO ANOTHER PLANET - A MANNED MISSION TO MARS.

EACH MISSION ... WILL LAY THE GROUNDWORK FOR THE NEXT."

THE ACTION: "... VICE PRESIDENT ... TO LEAD THE NATIONAL SPACE COUNCIL IN DETERMINING SPECIFICALLY WHAT'S NEEDED ...

- MONEY, MANPOWER, AND MATERIAL ...
- FEASIBILITY OF INTERNATIONAL COOPERATION ...
- REALISTIC TIMETABLES, MILESTONES ...

.. REPORT BACK AS SOON AS POSSIBLE WITH CONCRETE RECOMMENDATIONS"

PRE-JULY 20,1989 STUDIES

PATHWAYS

- Moon only-science
- Moon only-oasis
- Mars only
- Phobos --> Mars
- Moon --> Mars

MAJOR VARIABLES EXAMINED

- Launch vehicle size vs. in-space assembly vs. direct to surface
- SSF vs. new spaceport vs. direct assembly
- Spaceport in lunar orbit
- Various Mars trajectories: sprint, split/sprint, opposition, conjunction, Venus assist
- Chemical vs. electric vs. nuclear vs. unconventional propulsion
- Aerobraking vs. all-propulsive vehicles
- Expeditions vs. evolution
- Expendable vs. reusable spacecraft
- Propellant transfer vs. tank transfer
- Open vs. closed life support
- Zero-g vs. artificial-g Mars vehicle
- In-situ resources vs. Earth-supplied

POST-JULY 20,1989

PATHWAY SET:

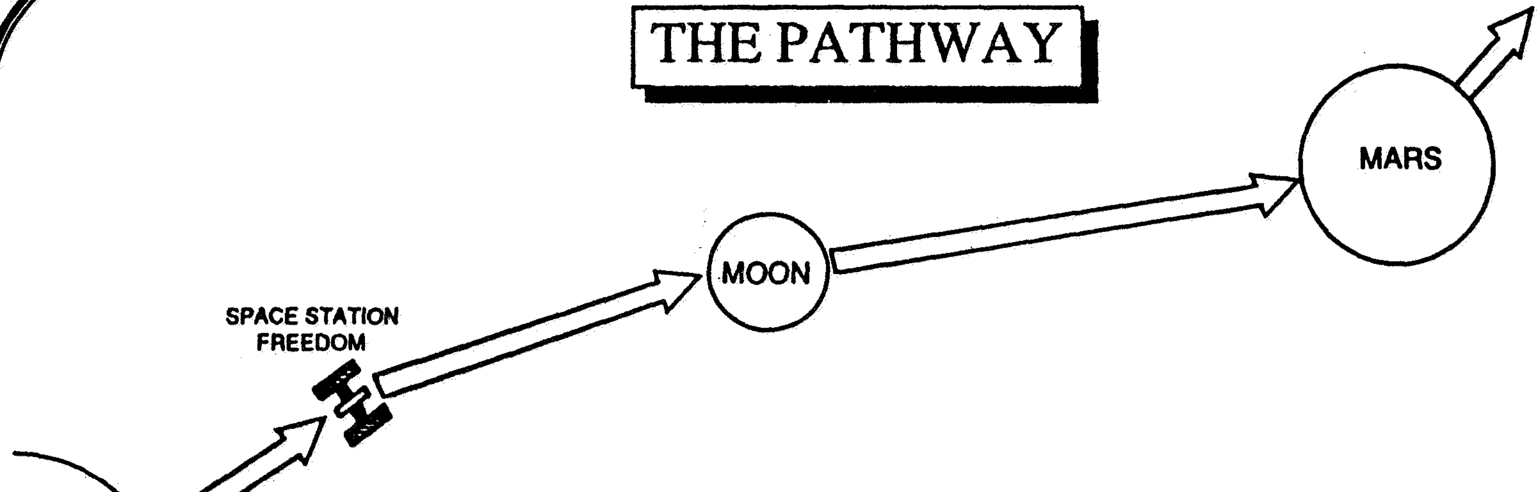
- SSF --> Moon --> Mars

MAJOR QUESTIONS

- Scale of program
- Program schedule
- Lunar emphasis
- Technology level
- Cost

NASA Exploration Initiative

THE PATHWAY



SPACE STATION FREEDOM	MOON	MARS
Late 1990's	First Decade	Second Decade

SPACE STATION FREEDOM — Late 1990's

- Permanently manned facility
- Science, technology, laboratory
- Spaceport for assembly, checkout, fueling, launch, servicing of lunar and Mars missions
- New technology experiments and demonstrations
- Life sciences/long-term human spaceflight research

MOON — First Decade

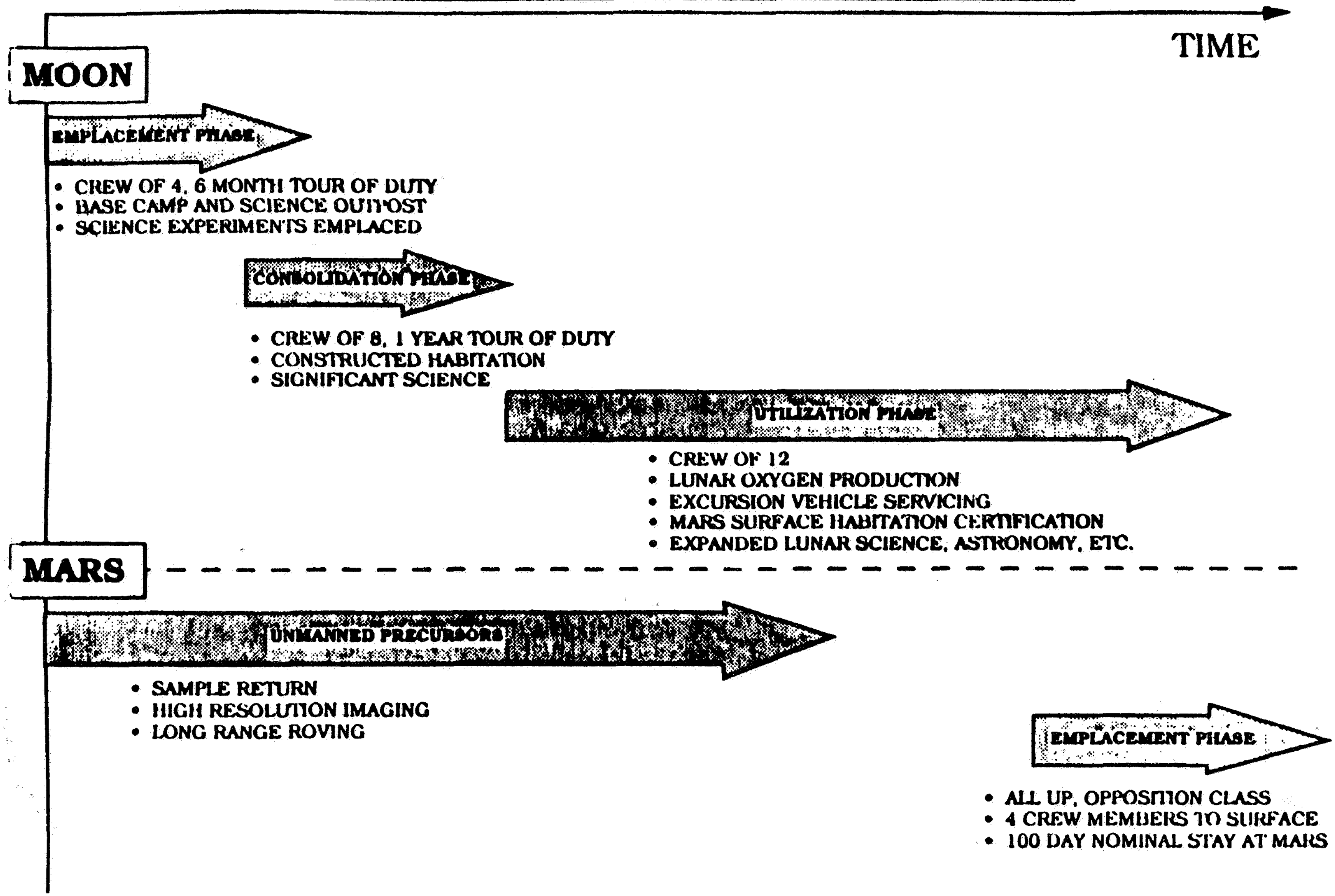
- Permanent outpost
- Science and exploration
  - Astronomy, physics, geology, life sciences
- Learn to live and work on an extraterrestrial surface with increasing self-sufficiency
  - Utilize local resources
  - Enable future industry
- Testbed to learn how to go to and survive on Mars
  - Simulate Mars mission

MARS — Second Decade

- First human landing on another planet
- Expedition --> outpost
- Science and exploration
- Live and work with a high degree of self-sufficiency
- Search for life: past or present

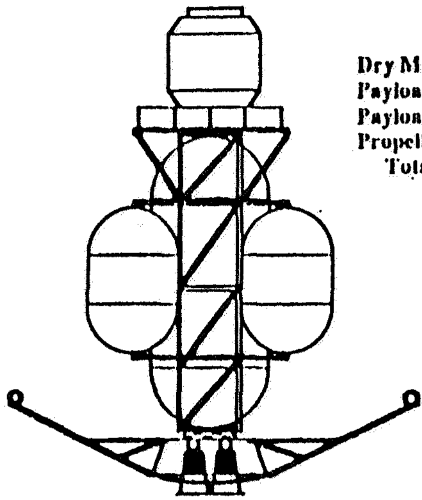
Technical Study Group

A POSSIBLE MISSION SCENARIO BASED ON EVOLUTIONARY APPROACH



LUNAR TRANSPORTATION VEHICLES
2003 - 2005

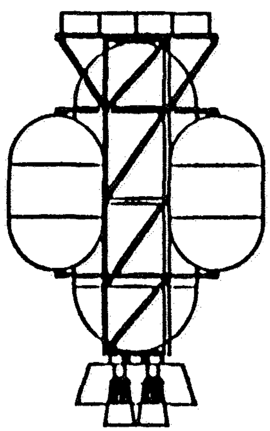
LUNAR TRANSFER VEHICLE



Dry Mass	18.7
Payload Out	54.8*
Payload Back	(1.2)
Propellant	146.6
Total Wet Mass	220.1

Engines:
Type : RS-44 Class
Thrust: 133.4 KN
Isp: 481 secs.
Number: 3

PILOTED CONFIGURATION

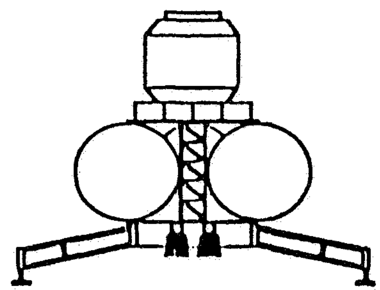


Dry Mass	7.8
Payload Out	64.6*
Payload Back	(0.0)
Propellant	124.1
Total Wet Mass	196.5

Engines:
Type : RS-44
Class
Thrust: 133.4 KN
Isp: 481 secs.
Number: 3

CARGO CONFIGURATION

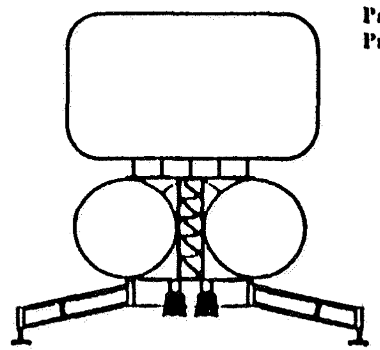
LUNAR EXCURSION VEHICLE



Dry Mass	6.3
Payload Down	23.7
Payload Up	(1.2)
Propellant	24.8
Total Wet Mass	54.8

Engines:
Type : RS-44 Class
Thrust: 266.9 KN
Isp: 465 secs.
Number: 4

PILOTED CONFIGURATION



Dry Mass	3.4
Payload Down	37.0
Payload Up	(0.0)
Propellant	24.2
Total Wet Mass	64.6

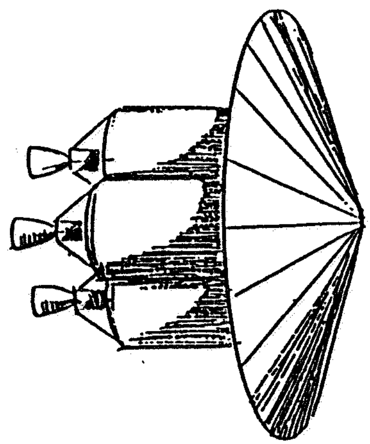
Engines:
Type : RS-44 Class
Thrust: 266.9 KN
Isp: 465 secs.
Number: 4

CARGO CONFIGURATION

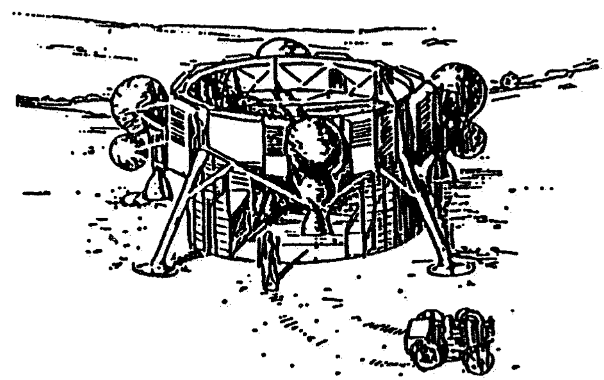
* Payload out includes wet excur' ·ehicle and payload

NASA

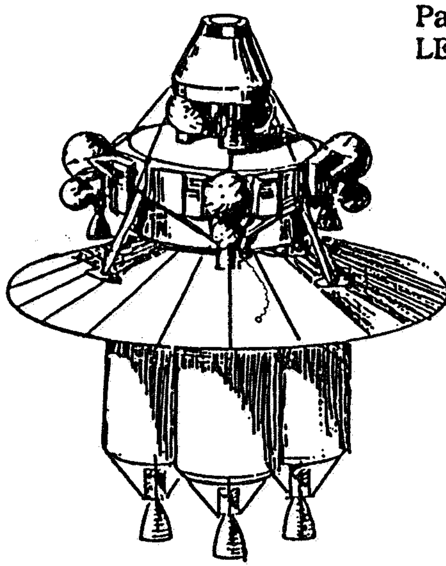
LUNAR TRANSFER, DESCENT, AND ASCENT VEHICLES

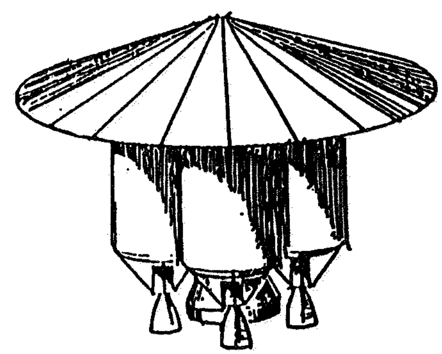


60 ft

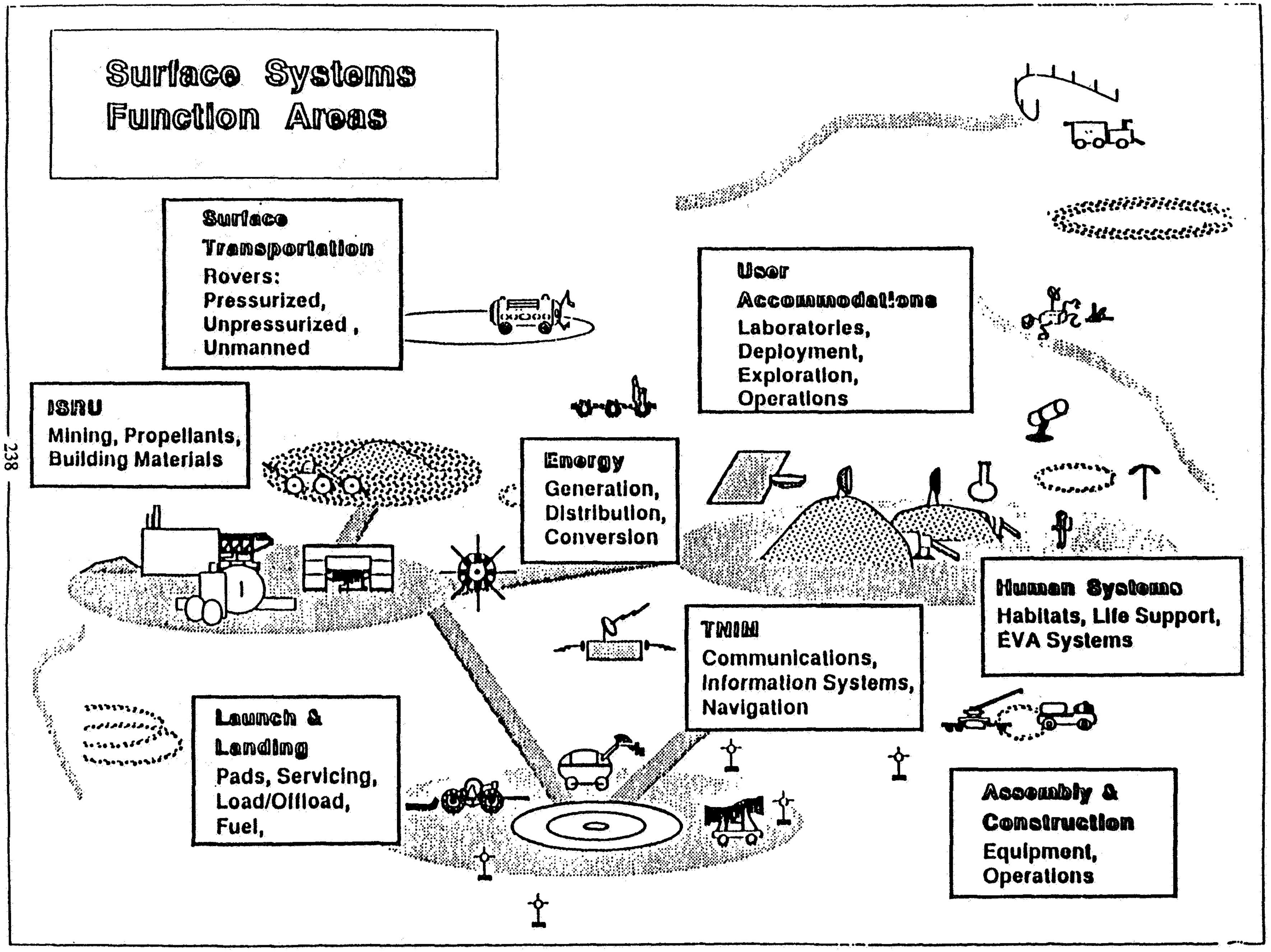


Payload = 44,000 lbs to surface
LEO mass = 316,000 lbs

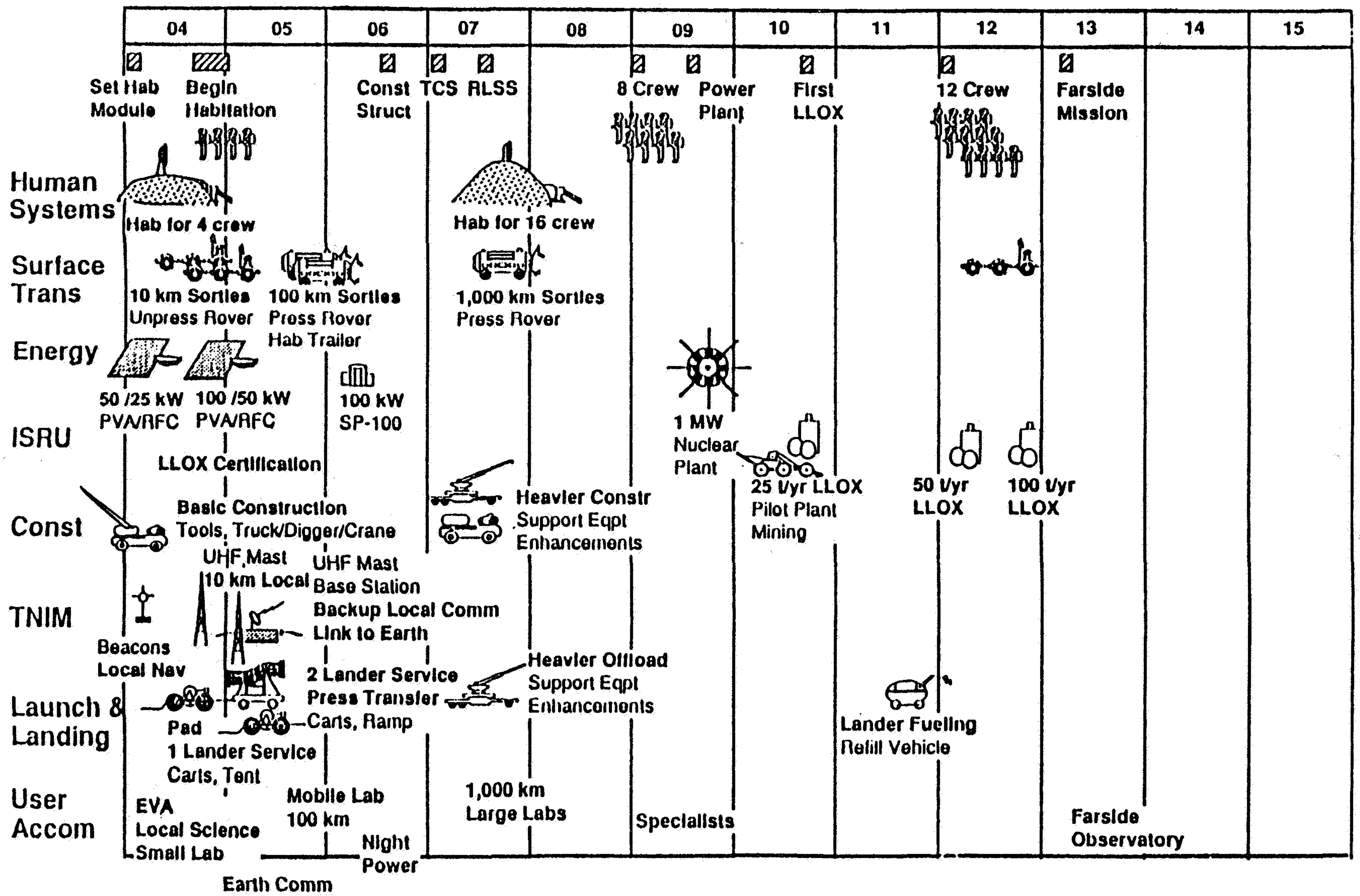




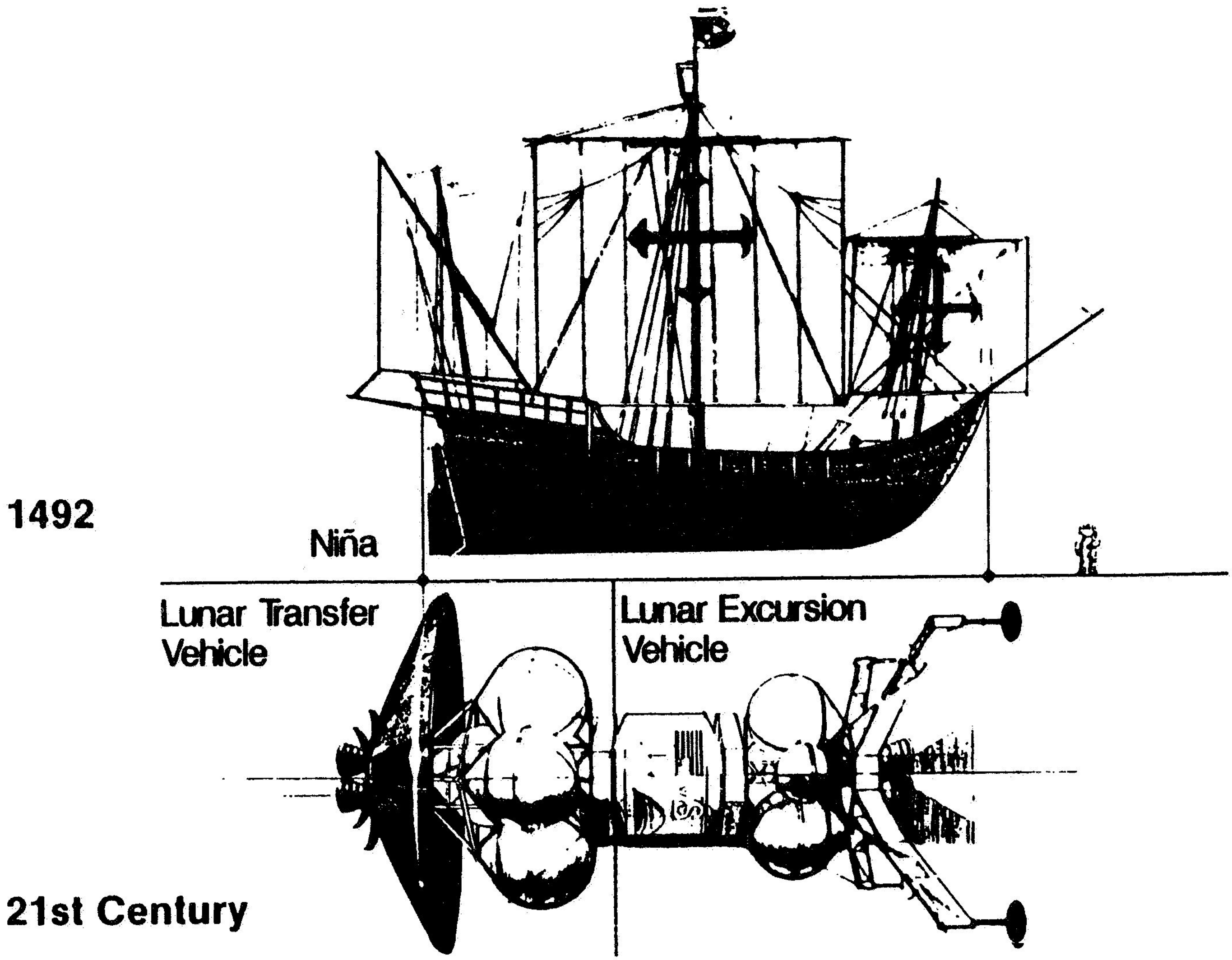
Office of Exploration


Surface Systems Function Areas
Surface Transportation
Rovers: Pressurized, Unpressurized , Unmanned
ISRU
Mining, Propellants, Building Materials
Energy
Generation, Distribution, Conversion
User Accommodations
Laboratories, Deployment, Exploration, Operations
Human Systems
Habitats, Life Support, EVA Systems
TNIM
Communications, Information Systems, Navigation
Launch & Landing
Pads, Servicing, Load/Offload, Fuel,
Assembly & Construction
Equipment, Operations

Lunar Evolution Summary

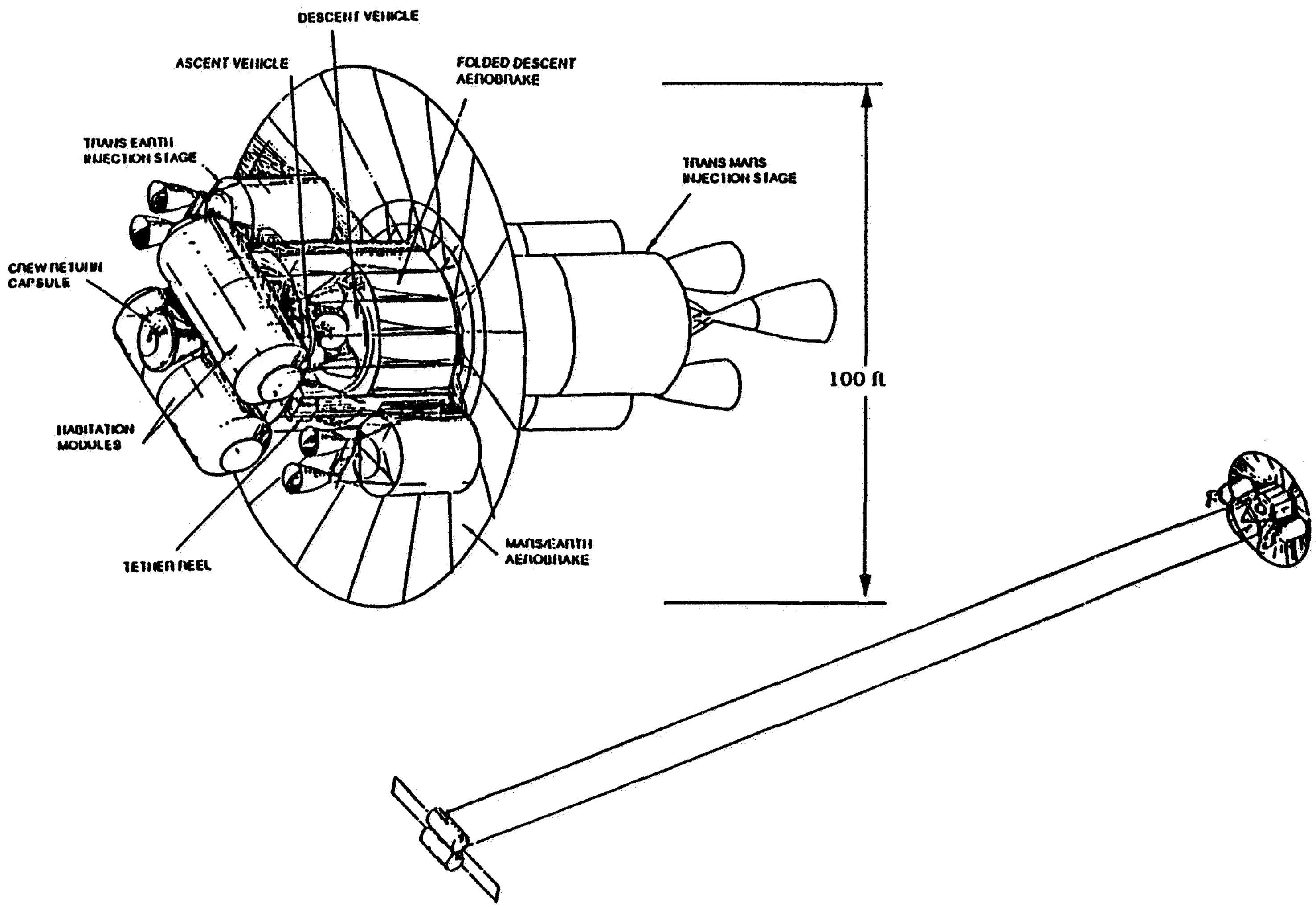


Ships of Exploration



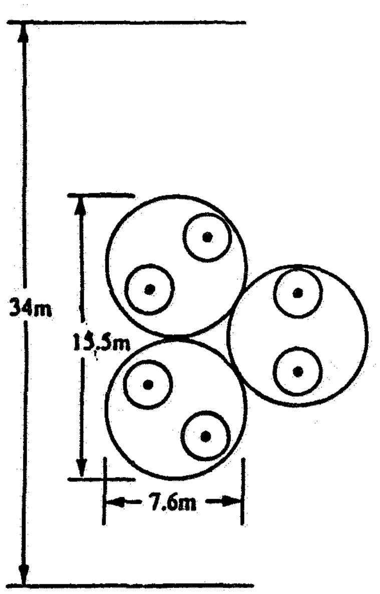
NASA

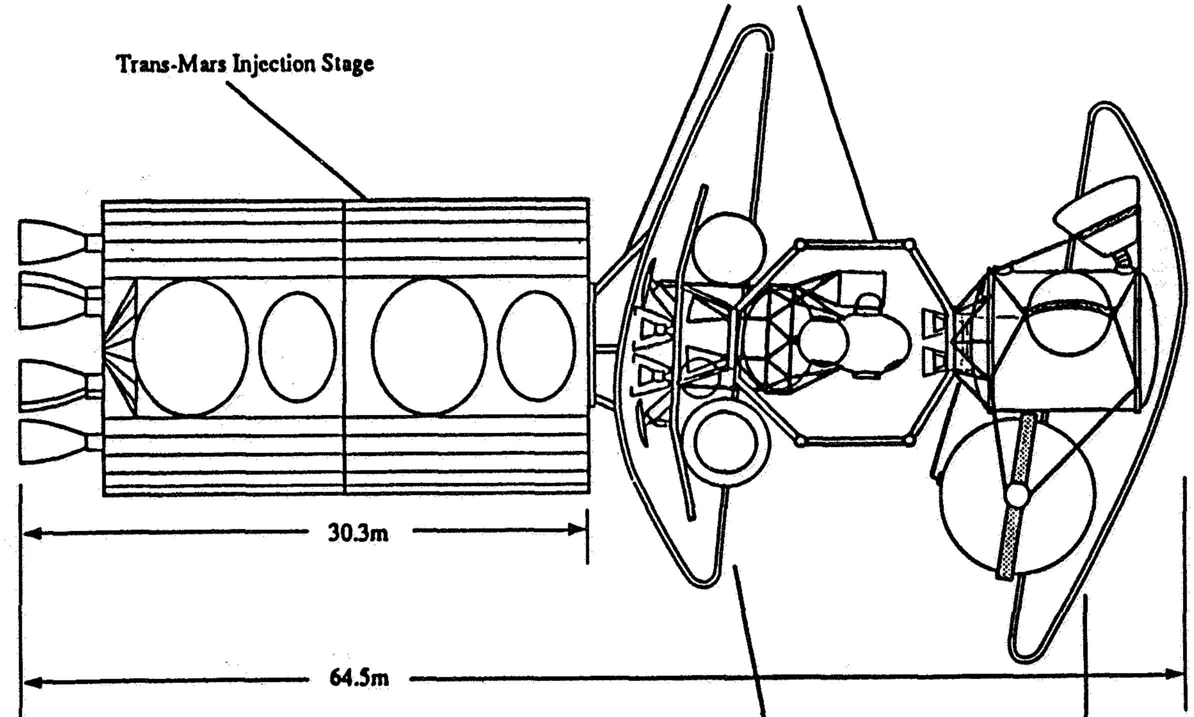
MARS SPACECRAFT



Office of Exploration

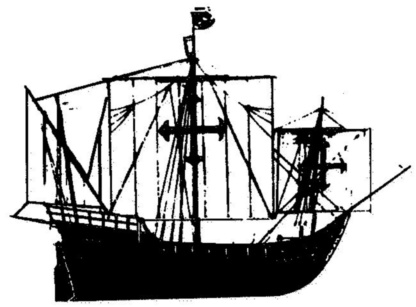
Full-up Mars Mission Vehicle in LEO





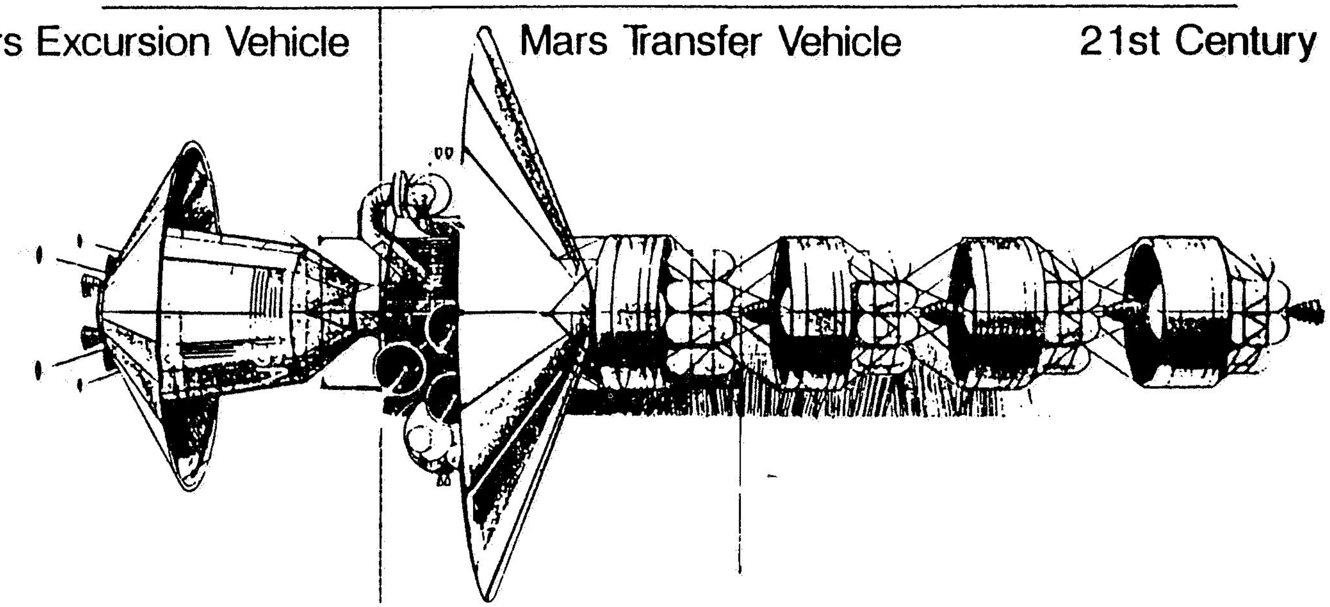
MTV	203.7t
MEV	81.6t
TMIS	526.4t
Total IMEO	811.7t

Ships of Exploration

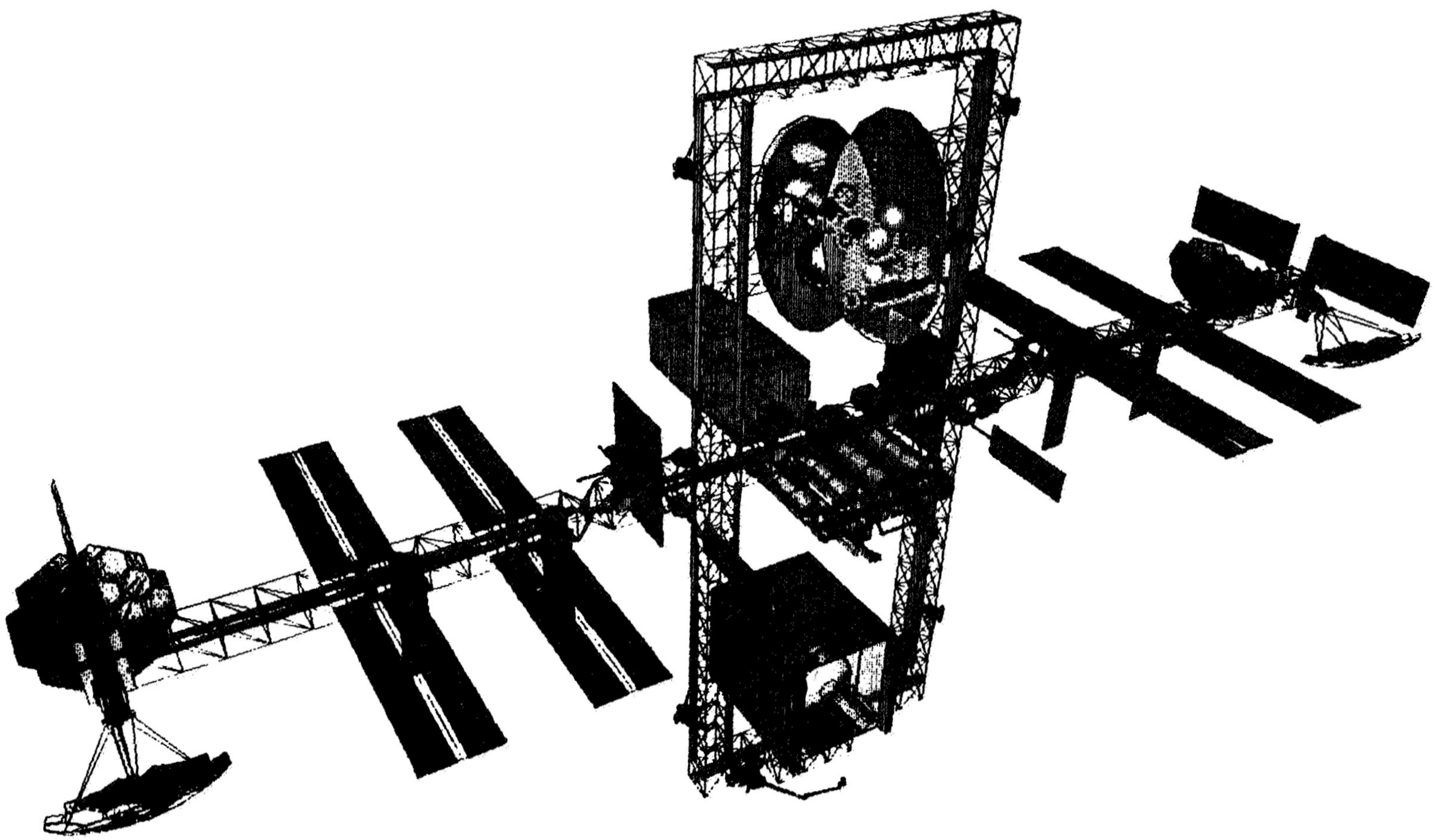


Niña 1492

Mars Excursion Vehicle | Mars Transfer Vehicle 21st Century

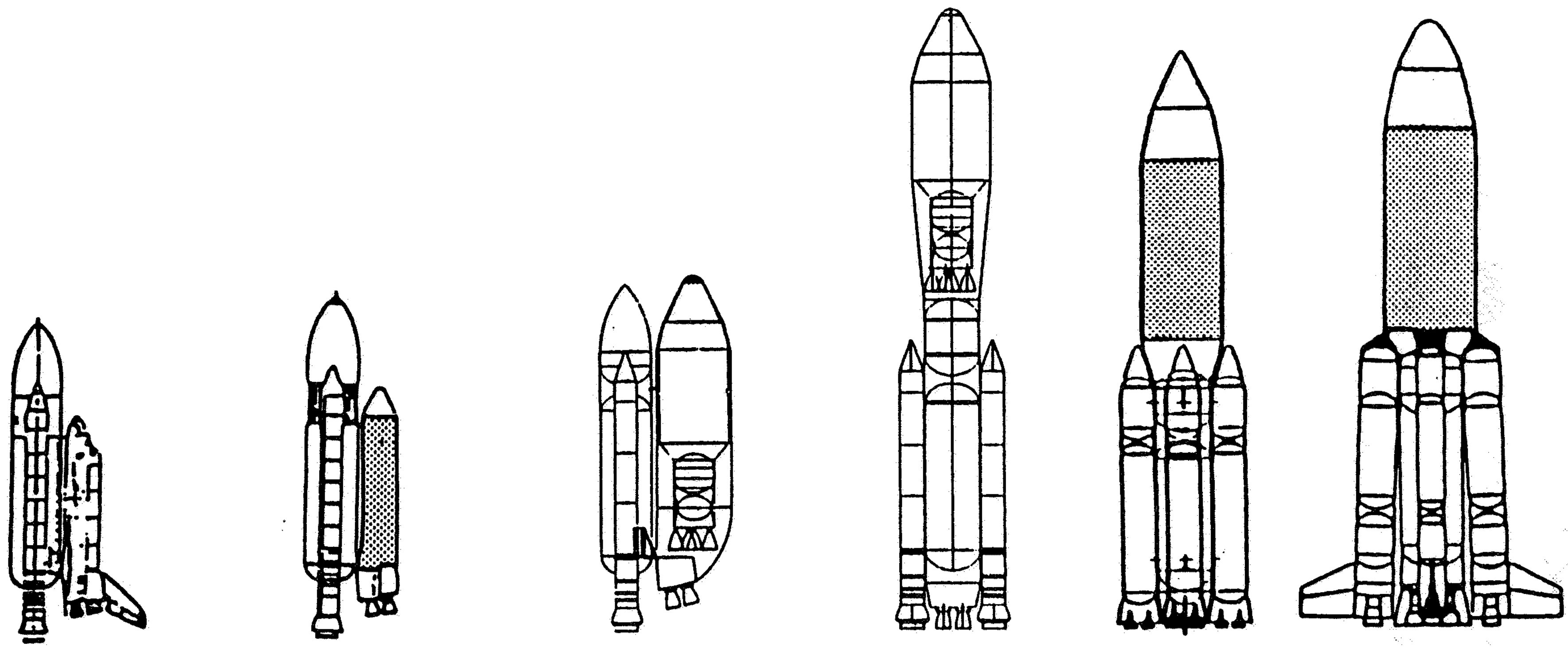


LUNAR/MARS TRANSPORTATION NODE



LaRC SSFO

SHUTTLE - DERIVED LAUNCH VEHICLES



STS	SHUTTLE C	SHUTTLE Z	SHUTTLE - DERIVED VEHICLES		
	SIDEMOUNT	SIDEMOUNT THIRD STAGE	INLINE THIRD STAGE MORE ASRMs	INLINE LIQUID STRAPONS	INLINE LIQUID STRAPONS BIGGER CORE

Lunar/Mars Space Transportation Systems Technology/Advanced Development

- Most Critical Areas of Technology/Advanced Development

<u>Lunar</u>

- Aerobrake
- Space Transfer Engine
- Cryogenic Storage and Transfer
- Cryogenic Aux. Propulsion

<u>Mars</u>

- Lightweight Aerobrakes
- Cryogenic Storage Transfer
- On-Orbit Assy & Veh Process.
- Space Transfer/Landing Engines
- ECLSS for Long-Duration Missions
- Alternate Propulsion Technology
  - Nuclear Thermal/Solar Electric

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30p

PRESENTATION 1.8

N91-17028

RELIABILITY AND QUALITY EEE PARTS ISSUES

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM

WILLIAMSBURG, VIRGINIA
NOVEMBER 7 - 9, 1989

RELIABILITY AND QUALITY EEE PARTS ISSUES

DAN BARNEY
MANAGER, EEE PARTS
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NASA

RELIABILITY AND QUALITY
EEE PARTS ISSUES

Dan Barney
Manager, EEE Parts
Safety, Reliability, Maintainability, & Quality Assurance
National Aeronautics and Space Administration

Irwin Feigenbaum
Supervisor, RM&QA Group
Space Operations
Vitro Corporation

BACKGROUND

The NASA Office of Safety, Reliability, Maintainability, and Quality Assurance (SRM&QA) provides a focal point for the overall development and implementation of NASA policies and procedures for safety and program/product assurance. Within the SRM&QA Office is the Reliability, Maintainability and Quality Assurance Division which has the following objectives as part of its charter:

- Formulate, recommend, implement and evaluate NASA RM&QA policies, procedures and standards.
- Establish technology development programs to ensure use of advanced assurance techniques.
- Plan and execute NASA product assurance activities.

Space transportation avionics activities represent a major effort relative to the overall NASA goals and missions. It is important to be aware of significant reliability and quality considerations such as the Electrical, Electronic, and Electromechanical (EEE) Parts program. This program is an important activity that impacts NASA reliability and quality.

EEE PARTS PROGRAM

This program establishes NASA policy and procedures governing the selection, testing, and application of EEE parts. Key program tasks include the following activities:

- Standardize parts through development and maintenance of a NASA Standard Parts List.
- Issue overall policy and requirements documents for control and management of parts.
- Develop and disseminate guidelines for parts application and use.

- Implement an EEE Parts Management Information System (EPIMS) to provide a database of parts usage and experience.

- Research programs directed at state-of-the-art methods of improving parts reliability such as investigations of advanced microelectronic devices and parts radiation effects.

- Develop general requirements relative to electronic packaging processes such as soldering, potting, and printed wiring.

EEE PARTS AND ASSOCIATED TECHNOLOGIES

Recent advances in the state-of-the-art of electronics parts and associated technologies can significantly impact the electronic designs and reliability of NASA space transportation avionics. This paper focuses on significant issues that result from these advances, including:

- *Recent advances in microelectronics technology (as applied to or considered for use in NASA projects).* These devices can provide significant improvements in design, performance, and reliability; and may be the only alternative to a feasible mission. However, there are problems associated with their use that must be considered and resolved.

- *Electronic packaging technology advances (concurrent with, and as a result of, the development of the advanced microelectronic devices).* A major source of electronic failure is packaging; thus, the applicable design/fabrication considerations must be addressed.

- *Availability of parts used in space avionics.* The uniqueness, small quantity, complexity, reliability, and environmental requirements for these parts and the associated design, fabrication, and testing also affect their availability. This should be recognized and considered in project management and control.

- *Standardization and integration of parts activities between projects, centers, and contractors.* The rapidly changing state-of-the-art accentuates the need for these activities. Therefore, applicable procedures are being developed and implemented.

ADVANCED MICROELECTRONICS

The developments in the design, fabrication, and application of advanced microelectronics have radically changed the approach to electronic system and component design. Application Specific Integrated Circuits (ASICs) are now available as mature parts and are being applied in new designs. The ASIC provides the design engineer with a flexibility to design circuits for specific applications to provide optimum performance and reliability. These circuits are all placed on a single device chip using

standard cells and associated design practices. However, increasing the reliability of devices (where every device is unique) is challenging designers to improve the reliability of the entire system.

The state-of-the-art for microelectronics has produced new, remarkable advances that are indicative of the devices that will soon find usage in NASA applications. There are devices available that contain an entire computer or 200,000 transistors on a single chip. Other devices use wafer scale integration, which results in a 4-inch chip with 35 million transistors. Such designs can provide the ability to incorporate fault detection or redundancy for improved reliability and 100 percent yields.

There are many other advances in microelectronic technology that are being applied in present designs and will proliferate to provide improvements in performance and reliability. Among the newer developments are devices with higher switching speeds, chips using smaller line geometries, Gallium Arsenide monolithic microwave integrated circuits and logic devices, hybrid circuits using discrete chips, and networks of thick and thin film resistors and capacitors. These developments miniaturize electronic functions from one-fifth to one-tenth of their original size.

The complexity of electronic designs in NASA vehicles has increased rapidly over the past 20 years, as depicted in Figure 1. The number of parts in a typical design of 20 years ago was 20,000; today's typical designs have 80,000 parts. However, the difference in parts count does not depict the true change in complexity. Some of the parts are integrated circuits containing a number of transistors in monolithic form, and the complexity and number of the integrated circuits used have increased during the 20-year period. Thus, using the number of transistors as a measure of complexity shows an increase from 80,000 to 60,000,000. The estimated complexity counts for a typical 1995 vehicle increase even further to 90,000 parts and 800,000,000 transistors. It should be noted that the straight line approximations shown indicate an exponential increase in complexity over time.

Space qualification of today's complex and customized devices is a costly and difficult process using the existing methods. Qualification entails testing a number of devices for all characteristics under various environmental conditions and for long periods of time. It becomes necessary to develop new, more efficient approaches to this process. Some of the methods being developed are as follows:

- *Qualification of a manufacturer's processes for fabricating devices (rather than qualification of each type of finished device).* This would result in a Qualified Manufacturers List (QML) in lieu of the current Qualified Products List (QPL) approach.

- *Fabricating areas of each chip with test patterns that could be tested to verify overall device suitability.* This would replace testing for each electrical characteristic of the device.

- *Qualifying libraries of standard cells and standard design practices that would be used in designing a device with many complex functions.* This would also require that the designer use approved rules in developing a custom device.

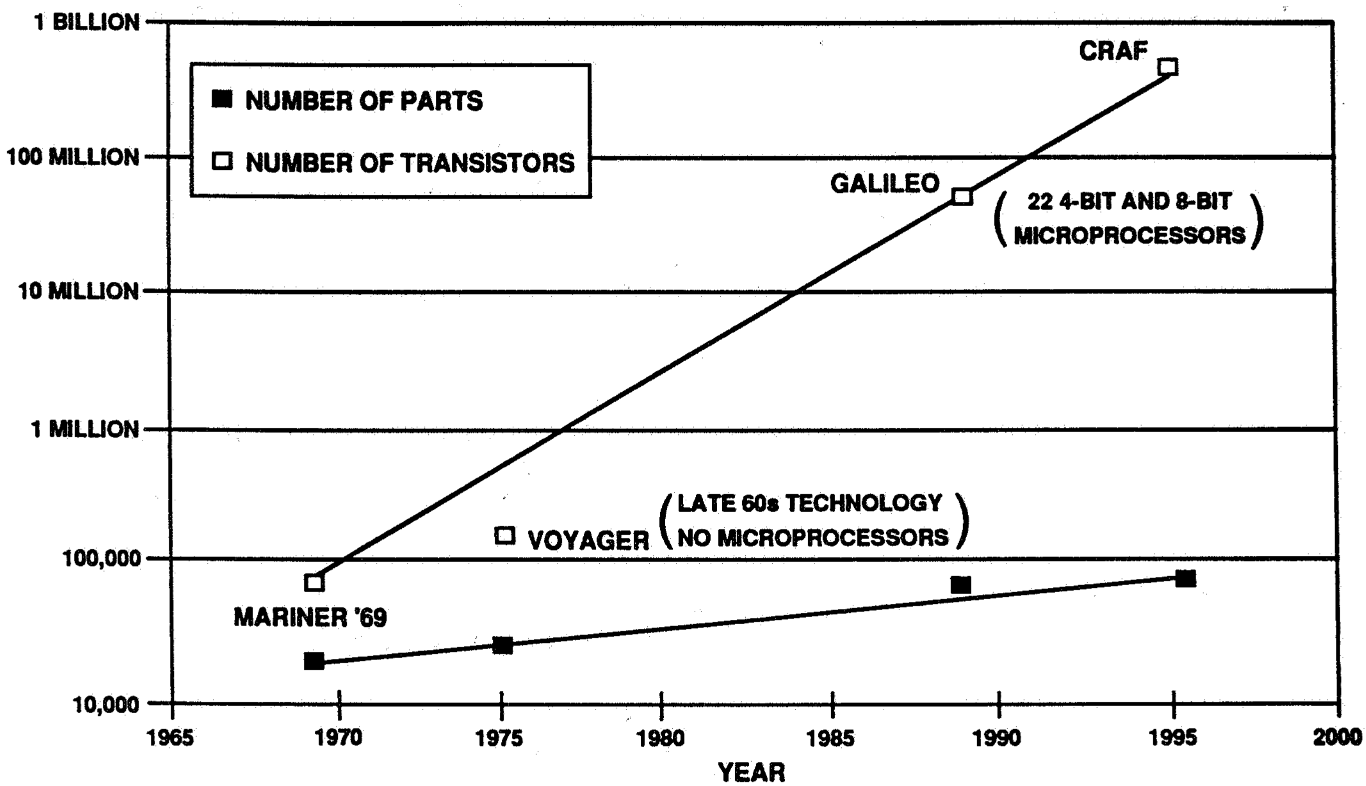


Figure 1. Increase in Space Electronic Complexity

ELECTRONIC PACKAGING

The use of advanced devices (which reduce size and increase performance and reliability) has resulted in radical changes in electronic packaging technology. While the focus is on ensuring the reliability of the devices, not enough attention is given to the circuit packaging methods used. Electronic packaging is a major source of electronic failures.

Surface mount technology is currently one of the strongest trends in electronic packaging. It uses devices as depicted in Figure 2, which have smaller packages and are reflow-soldered directly to the surface of a printed circuit board or substrate. This system allows for greater packaging density of parts, and often reduces the finished size of the end items as well as the number of modules used. Also, it permits packaging advanced microelectronic chips with a large number of inputs and outputs in chip carrier packages that can be leadless.

While surface mount technology has features that should increase reliability, it presents new failure modes that must be overcome. Thermal stresses associated with reflow soldering can produce cracking of packages and/or solder joints. Also, the process does not permit visual inspection of the solder joints. New design, workmanship, and inspection procedures must be developed to ensure adequate spacecraft reliability.

Hybrid microcircuits (see Figure 4) provide a method of packaging many small devices inside of one case to improve size and design flexibility. Chip devices are mounted on a substrate using either solder or conductive epoxy. Wires are then bonded to the chip and to terminals and the package is sealed. Two of the key factors for ensuring reliability of hybrid microcircuits include: (1) assembly performed in a clean area to prevent particle contamination, and (2) adequately controlled chip and wire bonds.

Assembly and packaging problems as depicted in Figure 5 show that these key factors also apply to older technologies. The problems associated with more advanced packaging can be more problematic.

Programs to provide reliable electronic packaging are needed to address these technologies. Efforts are underway to investigate possible process and testing improvements and controls, and update the NASA workmanship requirements documents for electronic packaging processes.

AVAILABILITY OF SPACE PARTS

The high reliability and small quantity requirements applicable to parts procured for space use result in unique problems with regard to their procurement and availability. Normal procurement times for high reliability parts suitable for space usage can be 1 to 3 years, due to special processing and test requirements. Also, space projects do not normally require large quantities of parts. Therefore, procedures should be instituted to: (1) provide for better availability; and (2) obviate use of less reliable parts, which can result in costly failures.

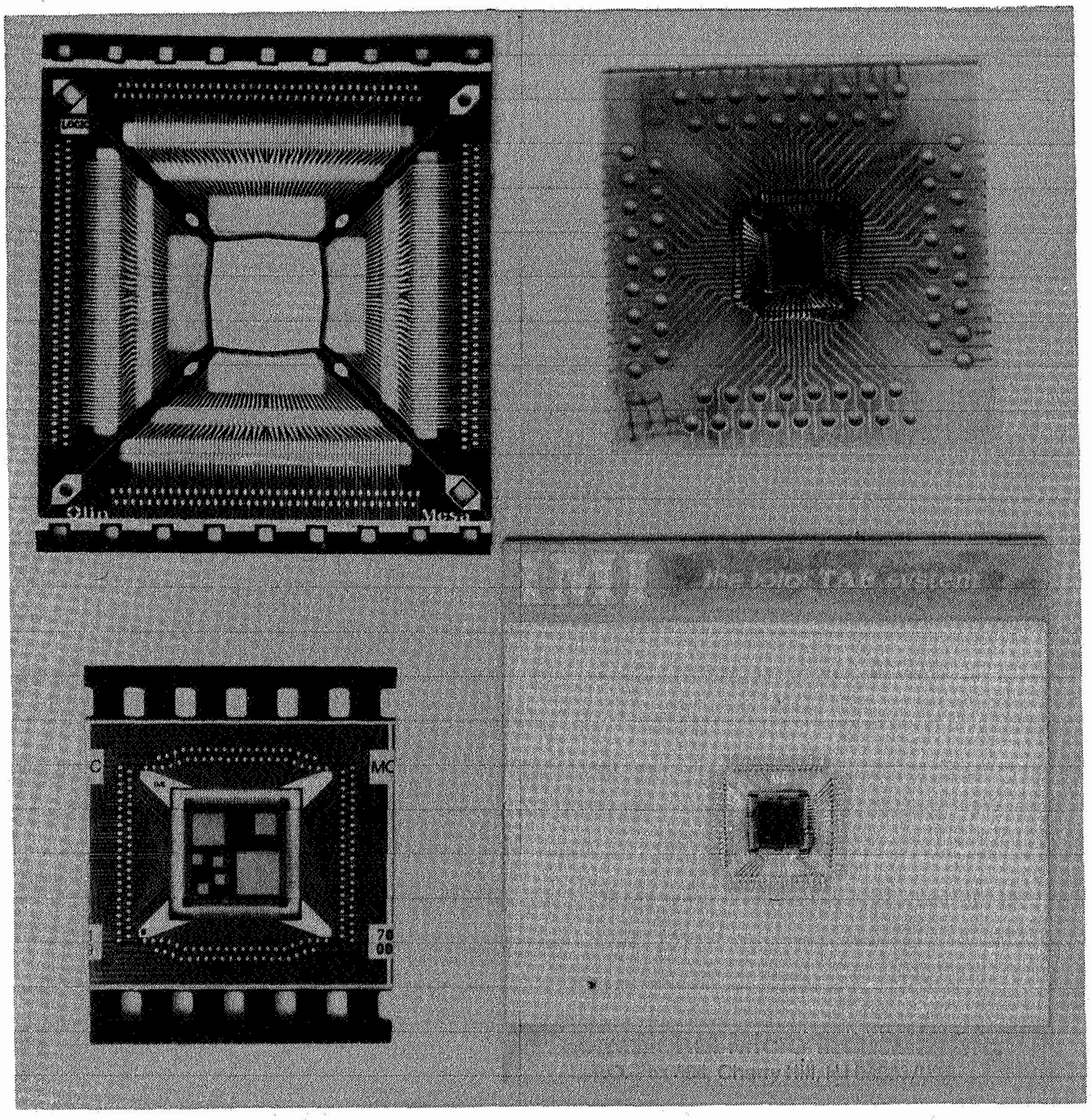


Figure 2. Examples of Surface-Mounted Devices

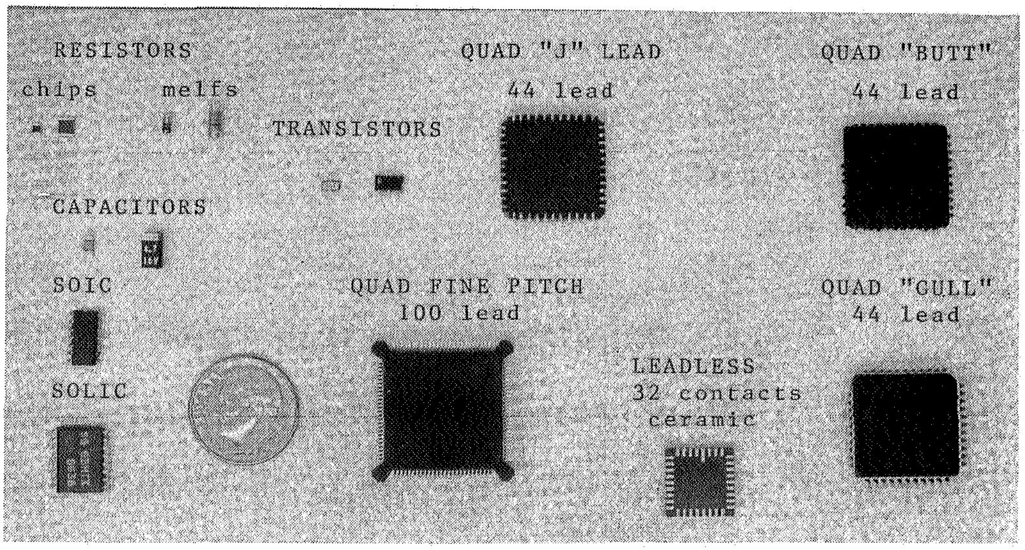


Figure 3. Example of Surface Mounted Devices

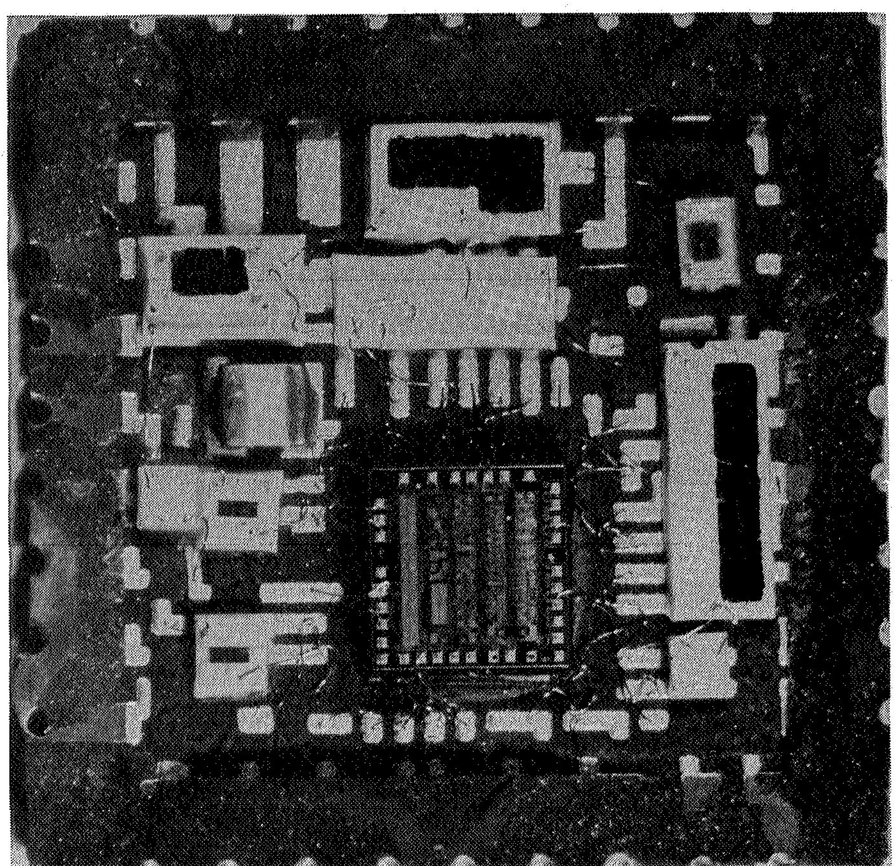
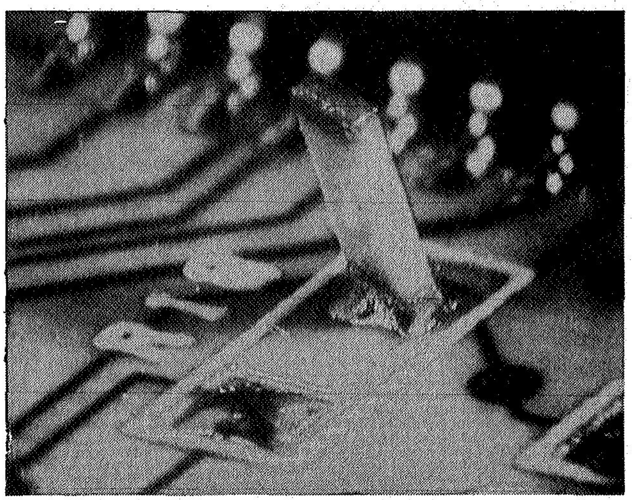


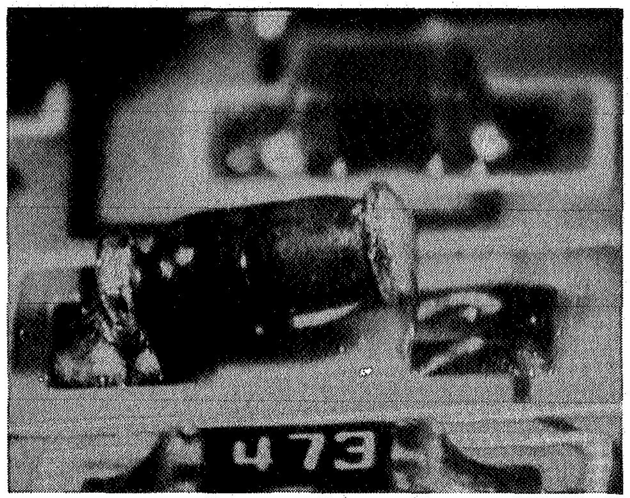
Figure 4. Example of Hybrid Device

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

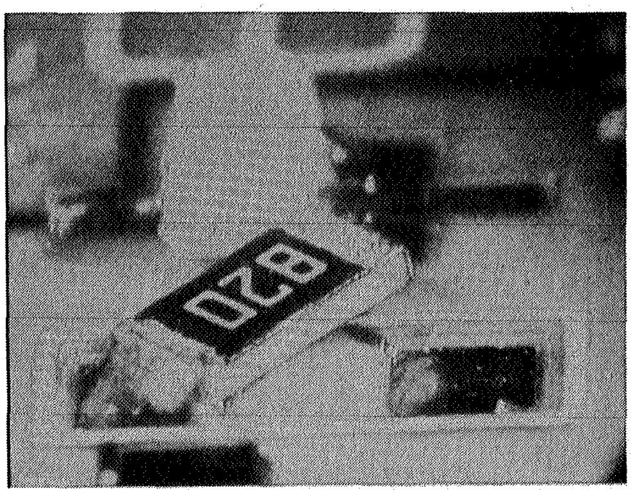
ORIGINAL PAGE IS
OF POOR QUALITY



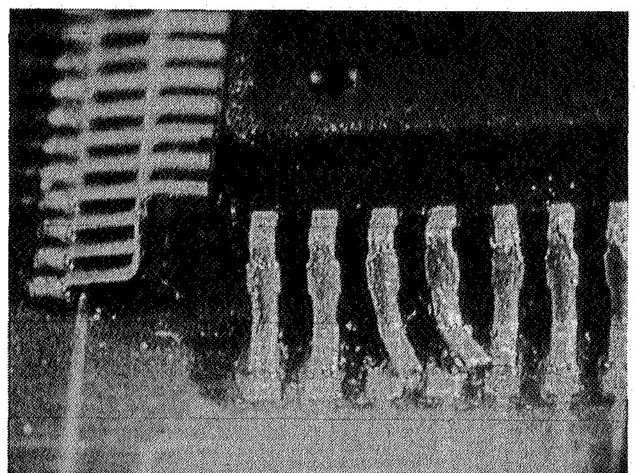
TOMBSTONING



A LIFTED MELF



POOR PLACEMENT OF A CHIP COMPONENT



A SWEEP OF TWO LEADS ON A GULL WING DEVICE

Figure 5. Examples of Assembling and Packaging Problems

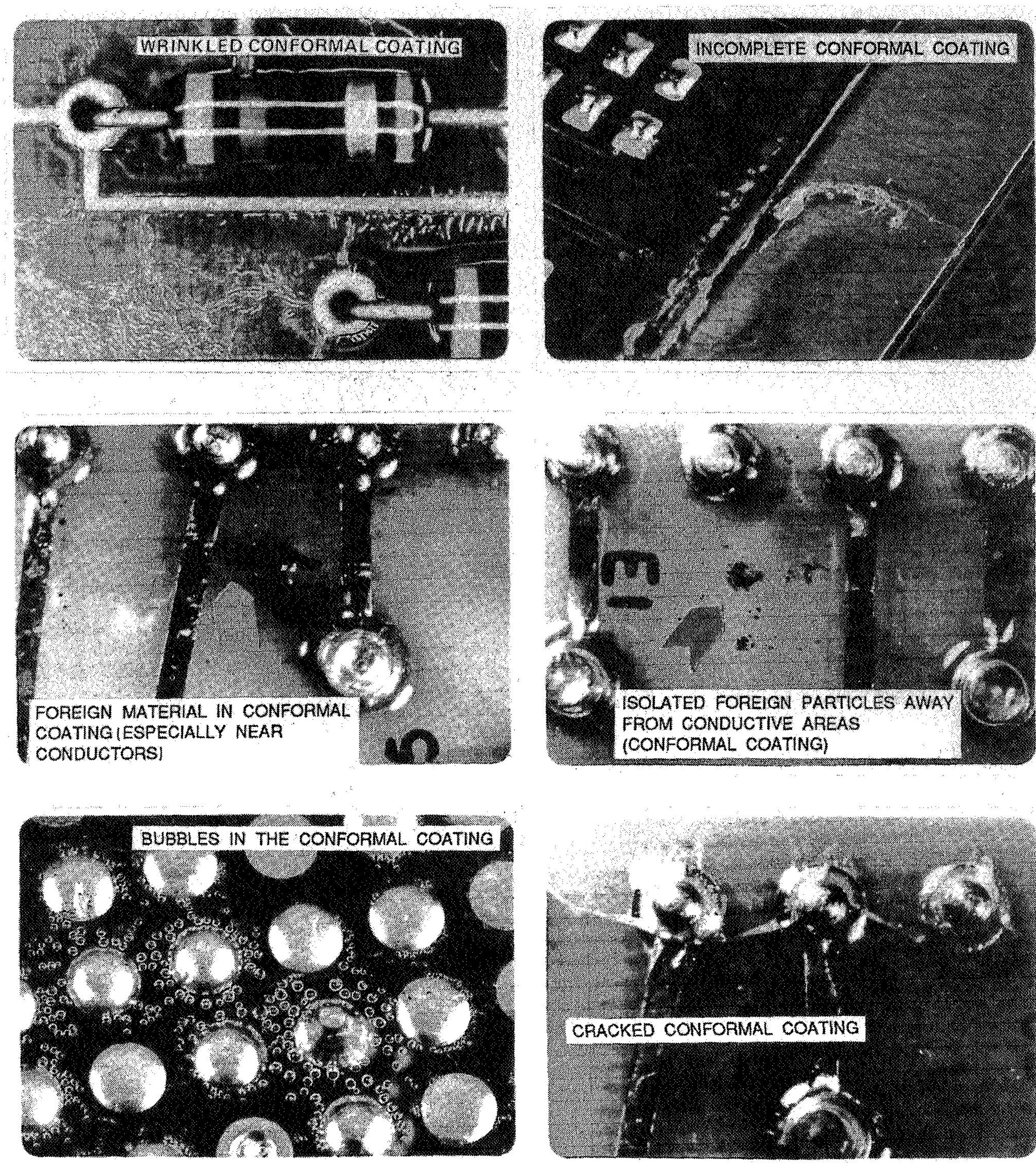


Figure 5. Examples of Assembling and Packaging Problems (Continued)

Standardization of parts can contribute to greater common usage and the ability to stock high reliability space parts. A "JAN S" stocking program was initiated for use by the U.S. Air Force, Space Division, and NASA projects and contractors. However, this program is not being utilized to a large extent and is in danger of being discontinued. It needs additional promotion and usage, and simplified authorization procedures.

The complexity and unique applications of advanced microelectronic devices further increase procurement time. Presently, there are no advanced microelectronic devices on an approved list. This hinders designers from using such parts. Procedures are being developed to overcome this problem.

A highly undesirable practice that results from parts unavailability is the cannibalism of parts from existing projects to meet the needs of new projects. Also, many parts become obsolete and are discontinued due to the development of improved parts. Therefore, the parts availability problem must be considered for new designs as well as for existing projects and the use of old designs on new projects.

INTEGRATION OF PARTS ACTIVITIES

The new developments in parts technology emphasize the need for interchange and dissemination of information between NASA projects, centers, and contractors. This is important to avoid duplication of effort, and also provide a basis for standardization and common usage of advanced devices. Therefore, cost savings, standardization, and earlier detection of problems will significantly improve the success of the project.

The availability of highly reliable parts for space use is affected by the relatively small quantities of parts required for each space project. The space quality parts requirements represent only a minute percentage of the overall market for parts manufacturers. This is compounded by current practices in which there are separate procurements of the same types of parts on each project and even by centers/contractors on the same project. Increased emphasis must be placed on centralized procurement activities.

The NASA Standard Parts Program provides for better standardization of parts through the following documents:

- MIL-STD-975, NASA Standard Parts List
- MIL-HDBK-978, Application of NASA Standard Parts
- NHB 5300.4(1F), Parts Management and Control Requirements for EEE Parts

It is important that these documents be continuously used and updated to promote standardization, improve reliability, and provide a basis for introduction and use of advanced microelectronic devices.

The information data base of EEE parts, EPIMS, is being developed and will be operational in the first quarter of 1990. It will contain NASA EEE parts data from all projects as well as applicable data from the Department of Defense and the Defense

Nuclear Agency. The goal of EPIMS is to disseminate EEE parts data to the design engineer, and consolidate information to form the basis for standardized and centralized procurement practices.

SUMMARY

The recent advances in electronic parts technology provide an important means for improving the performance and reliability of NASA space transportation projects. These upgrades are being incorporated into many electronic design efforts and their usage will increase as even more advances are introduced. However, this creates new challenges as techniques must be refined or adapted and procedures developed or revised to implement the most advanced technology for reliable space systems.

NASA STANDARD PARTS PROGRAM VIDEO PRESENTATION

ELECTRICAL, ELECTRONIC, AND ELECTROMECHANICAL PARTS FOR SPACE SYSTEMS

DANIEL BARNEY, MANAGER EEE PARTS
RELIABILITY, MAINTAINABILITY, AND QUALITY ASSURANCE DIVISION
NOVEMBER 7, 1989

NASA

ELECTRICAL, ELECTRONIC, AND ELECTROMECHANICAL PARTS FOR SPACE SYSTEM

SAFETY, RELIABILITY, MAINTAINABILITY AND QUALITY ASSURANCE

- **PURPOSE OF VIDEO – NEED FOR HIGH RELIABILITY PARTS**
- **QUANTITY AND COMPLEXITY**
  - 100,000s OF TRANSISTORS ON EACH CHIP
  - MILLIONS OF INTERCONNECTED PARTS
- **REQUIREMENTS**
  - ***ALL*** PARTS MUST FUNCTION WHEN TURNED "ON"
  - PARTS MUST REMAIN OPERATIONAL THROUGHOUT MISSION IN HOSTILE ENVIRONMENT
- **PARTS PROCUREMENT – CONTRACTOR ON EACH SPACE PROJECT MAKES SMALL BUYS, WHICH CAUSES:**
  - HIGH UNIT COST
  - MINIMAL OR NO MARKET INFLUENCE
  - REDUCED RELIABILITY AND STANDARDIZATION

NASA

ELECTRICAL, ELECTRONIC, AND ELECTROMECHANICAL PARTS FOR SPACE SYSTEM (CONT.)

SAFETY, RELIABILITY, MAINTAINABILITY AND QUALITY ASSURANCE

- PART FAILURES ARE *VERY* COSTLY AND RESULT IN:
  - LAUNCH ABORT
  - LOSS OF MISSION
  - SAFETY HAZARD

- PART FAILURE COST INCREASES EXPONENTIALLY
  - $100s AT PRINTED CIRCUIT BOARD LEVEL
  - $1,000s AT BOX LEVEL
  - 10,000s AT SUBSYSTEM LEVEL
  - $100,000s AT SYSTEM LEVEL
  - $1,000,000+ ON SPACECRAFT (e.g., Shuttle Crew Repair of Satellite In Space)

NASA

NASA STANDARD PARTS PROGRAM

*SAFETY,
RELIABILITY,
MAINTAINABILITY
AND
QUALITY ASSURANCE*

- **FUNCTION – INTEGRATE CENTERS, PROJECTS, AND CONTRACTORS**
  - SET STANDARDS AND ENVIRONMENTAL REQUIREMENTS
  - PREPARE SPECIFICATIONS, PERFORM FAILURE ANALYSIS
- **OBJECTIVES**
  - REDUCE COST
  - INCREASE RELIABILITY
  - STREAMLINE PROCUREMENT
- **KEY DOCUMENTATION**
  - NHB 5300.4(1F), STANDARD SPACE PARTS REQUIREMENTS
  - MIL-STD-975, LIST OF STANDARD SPACE PARTS
  - MIL-HDBK-978, APPLICATION OF STANDARD PARTS
  - MIL-STD-883, STANDARD PARTS TESTING
  - EEE PARTS INFORMATION MANAGEMENT SYSTEM (EPIMS)

A COPY OF THE VIDEO IS AVAILABLE FROM MR. DWAYNE BROWN, NASA CODE Q PUBLIC AFFAIRS OFFICER, (202) 453-8956

NASA

EEE PARTS ISSUES

*SAFETY,
RELIABILITY,
MAINTAINABILITY
AND
QUALITY ASSURANCE*

- ADVANCED MICROELECTRONICS
- ELECTRONIC PACKAGING RELIABILITY
- AVAILABILITY OF PARTS
- INTEGRATION OF PARTS ACTIVITIES

NASA

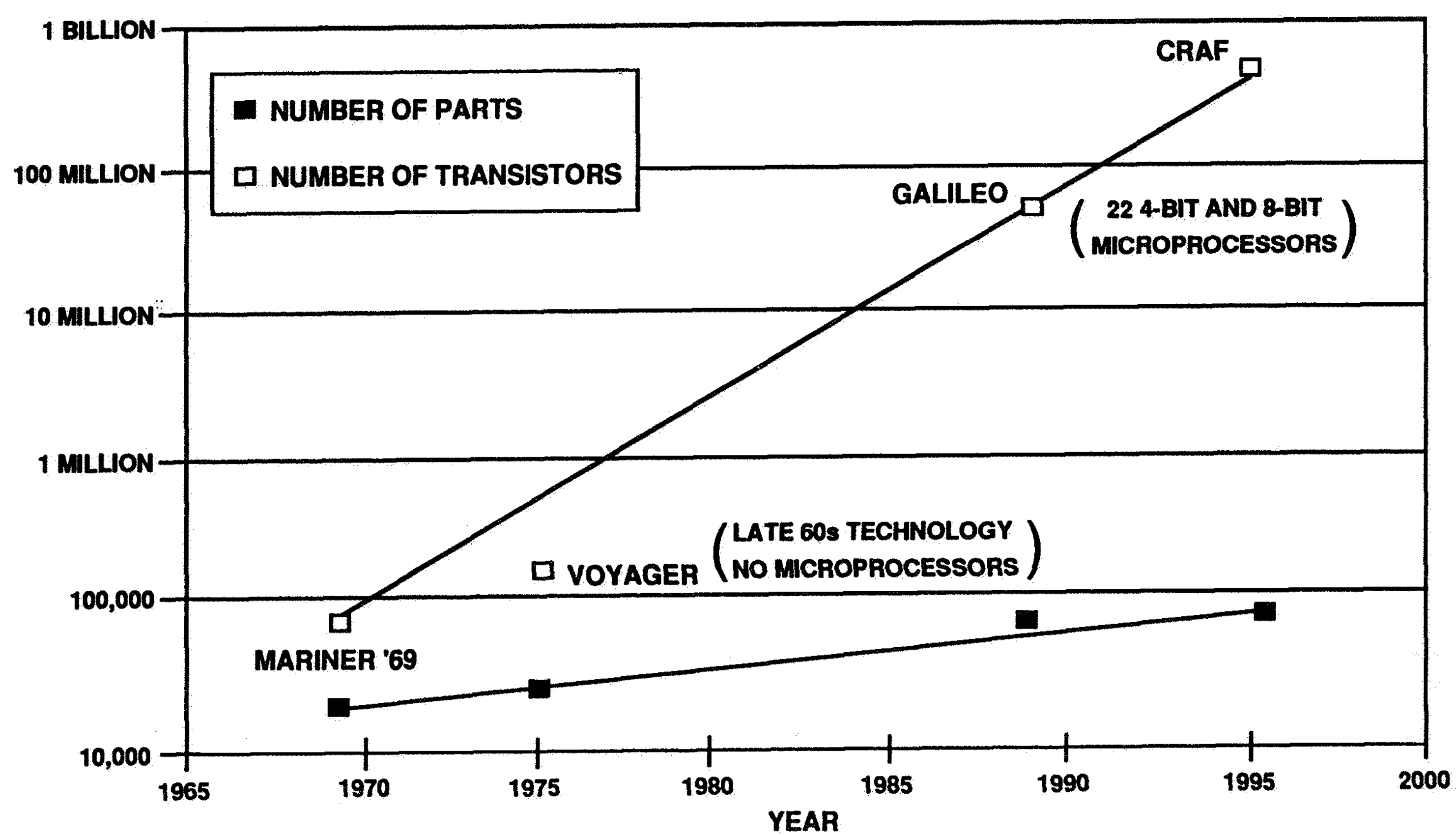
ADVANCED MICROELECTRONICS ISSUES

SAFETY, RELIABILITY, MAINTAINABILITY AND QUALITY ASSURANCE

- APPLICATION SPECIFIC INTEGRATED CIRCUITS (ASIC)
- ENTIRE COMPUTER OR 200,000 TRANSISTORS ON A CHIP
- FAULT DETECTION/REDUNDANCY - CHIP WITH 35 MILLION TRANSISTORS
- SPEED, LINE GEOMETRIES, GALLIUM ARSENIDE, 3-DIMENSIONAL, HYBRIDS, DISCRETE NETWORKS

INCREASE IN SPACE ELECTRONIC COMPLEXITY

SAFETY, RELIABILITY, MAINTAINABILITY AND QUALITY ASSURANCE



NASA

SPACE QUALIFICATION OF ADVANCED MICROELECTRONICS

SAFETY, RELIABILITY, MAINTAINABILITY AND QUALITY ASSURANCE

APPROACH

- QUALIFIED MANUFACTURERS LIST
  - PROCESS INSTEAD OF FINISHED DEVICE
- TESTING BASED ON INCREASED COMPLEXITY
  - AREAS OF CHIP USED FOR TESTING, SOME DEVICES ARE SO FAST THAT THEY CANNOT BE TESTED
- STANDARDIZATION OF DESIGN
  - DESIGN RULES AND STANDARD CELLS

NASA

ELECTRONIC PACKAGING ISSUES

SAFETY, RELIABILITY, MAINTAINABILITY AND QUALITY ASSURANCE

- MAJOR SOURCE OF ELECTRONIC FAILURES
  - SURFACE MOUNT DEVICES
  - HYBRIDS
  - WIRE BONDS
  - SOLDER JOINTS
- INSPECTION IS DIFFICULT
- RELIABILITY IMPROVEMENT PROGRAM IS NEEDED

SAFETY,
RELIABILITY,
MAINTAINABILITY
AND
QUALITY ASSURANCE

AVAILABILITY OF SPACE PARTS

- LONG PROCUREMENT TIMES (UP TO 3 YEARS) (BOTH ADVANCED AND APPROVED PARTS)
- NO ADVANCED MICROELECTRONIC PARTS ARE ON AN APPROVED LIST
- STOCKING PROGRAM UNDER-UTILIZED
- CANNIBALISM PRACTICES
- OBSOLESCENT/DISCONTINUED PARTS

NASA

SOLUTIONS: INTEGRATION OF PARTS ACTIVITIES

SAFETY, RELIABILITY, MAINTAINABILITY AND QUALITY ASSURANCE

- INTEGRATION AND COORDINATION BETWEEN CENTERS, PROJECTS, AND CONTRACTORS
- NEED FOR CONSOLIDATED PROCUREMENTS
- IMPROVED RELIABILITY THROUGH STANDARDIZATION
  - MIL-STD-975, NASA STANDARD PARTS LIST
  - MIL-HDBK-978, APPLICATION GUIDE
  - NHB 5300.4(1F), EEE PARTS REQUIREMENTS
- USE OF COMMON DATA BASE, EEE PARTS INFORMATION MANAGEMENT SYSTEM (EPIMS)

NASA

SUMMARY

*SAFETY,
RELIABILITY,
MAINTAINABILITY
AND
QUALITY ASSURANCE*

ISSUES:

- SPACE QUALIFICATION OF ADVANCED MICROELECTRONICS
- IMPROVED ELECTRONIC PACKAGING RELIABILITY
- SPACE PARTS AVAILABILITY PROBLEMS

SOLUTION:

- STANDARDIZATION AND INTEGRATION OF PARTS ACTIVITIES

PANEL OVERVIEW AND INTRODUCTION PRESENTATIONS

- OPERATIONAL EFFICIENCY
- FLIGHT ELEMENTS
- PAYLOAD ACCOMMODATIONS
- SYSTEMS ENGINEERING AND INTEGRATION (SE&I)

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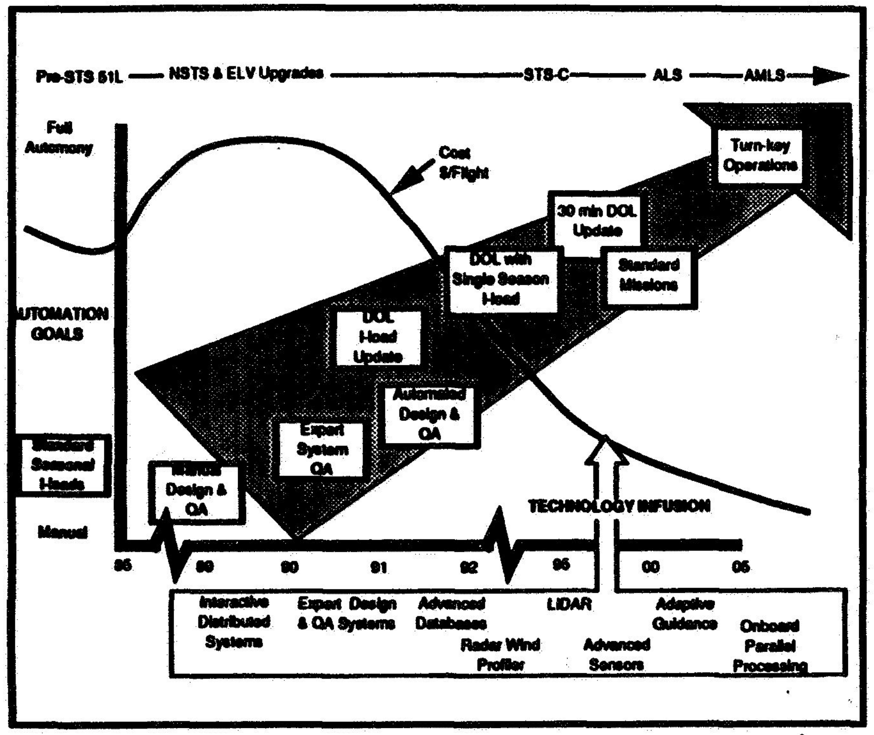
PRESENTATION 2.1

N91-17029

OPERATIONAL EFFICIENCY

SPACE TRANSPORTATION TECHNOLOGY SYMPOSIUM
OPERATIONAL EFFICIENCY
AUTOMATIC ASCENT FLIGHT DESIGN

NOVEMBER 1989



MAJOR OBJECTIVES

- Enhance Hardware and Software with New Automated Design Tools and Distributed Equipment
- Reduce Costs
- Increase Launch Probability
- Improve Flight Design Quality Assurance
- Reduce Flight Design Timeline / Increase Responsiveness
- Standardized Training Techniques and Tools
- Develop Onboard Targeting & Autonomous Guidance

KEY CONTACTS

- E. M. Henderson - JSC / DM
  - Rockwell Shuttle Operations Co.
- A. J. Bordano - JSC / FM
  - McDonnell Douglas Space Systems Co.

Facilities:

- Flight Design Computational Facility - JSC / DM
  - Flight Analysis and Design System (FADS)
- MPAD Prototyping Lab - JSC / FM
- Shuttle Avionics Integration Lab (SAIL) - JSC / EA

MAJOR MILESTONES (1990-2005)

Technology Availability:	Products:	
Interactive / Distributed Systems		Today
Flight Design Expert Systems		
	Day of Launch I-load Update	1990
Advanced DB's for Flight Design		1991
	Expert System I-load Verif.	
	Auto I-load Design	1992
Radar Wind Profiler	FADS	1993
	FSW for single season I-load	
Adaptive Guidance Algorithms		1995
LIDAR Technology		1997
Advanced Sensors	30 min DOL I-load Design	1998
Flight Qualified Parallel Proc.		2000
	Onboard Autonomy	2005

SPACE TRANSPORTATION TECHNOLOGY SYMPOSIUM
OPERATIONAL EFFICIENCY
AUTOMATIC ASCENT FLIGHT DESIGN

NOVEMBER 1989

TECHNOLOGY ISSUES

- Distributed Processing
- Advanced Software / Database Technology
- Ground vs. Onboard Automation
- Ground vs. Onboard wind sensing/processing
- Advanced Sensors/Processing
  - Winds
  - Air Loads
  - Air Data
- Autonomous Abort Capability
- Onboard Parallel Processing for GN&C applications

CANDIDATE PROGRAMS

- STS / STS Evolution / ASRM
- ELV'S
- STS - C
- ALS
- AMLS
- Lunar / Mars Initiative

MAJOR ACCOMPLISHMENTS

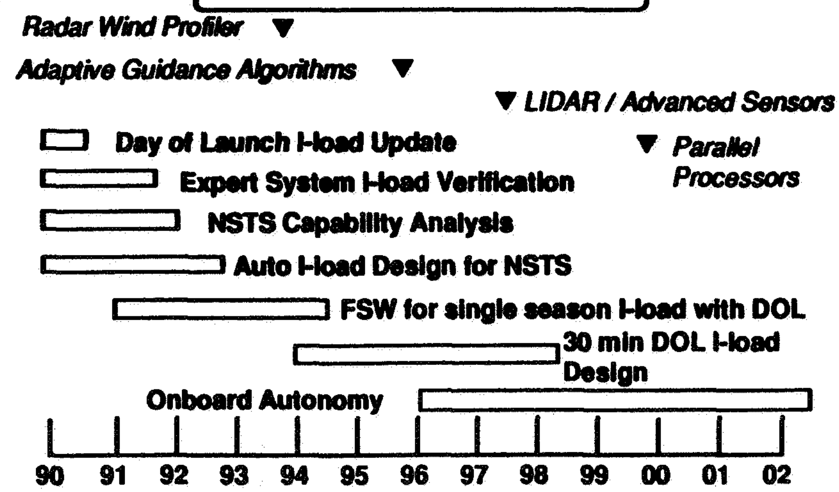
Implemented

- Alternate Iloads
- Adaptive Guidance Throttling

Demonstrated Capability

- Automated Day-of-Launch I-load generation & verification
- Automated Flight Design verification (partial)
- Single Season I-load for NSTS
- Onboard Targeting Algorithm for NSTS

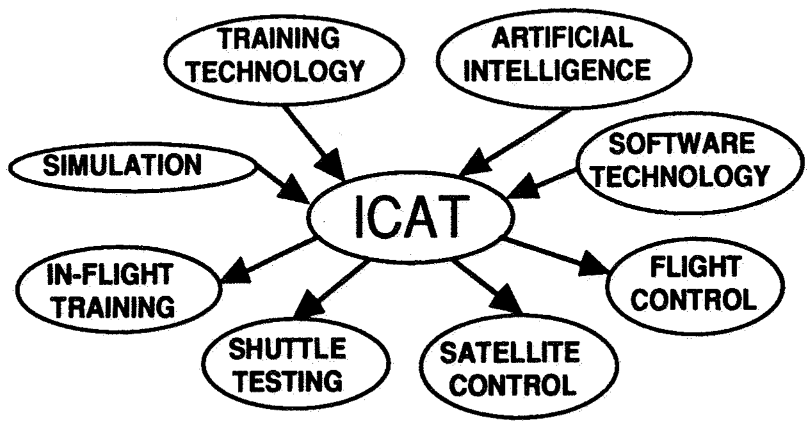
SIGNIFICANT MILESTONES



SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
OPERATIONAL EFFICIENCY
ADVANCED TRAINING SYSTEMS

NOVEMBER 1989

ADVANCED AVIONICS CONCEPTS



MAJOR OBJECTIVES:

DISTRIBUTED INTELLIGENT SYSTEMS FOR TRAINING IN COMPLEX, MISSION-CRITICAL TASKS THAT

- ARE ADAPTIVE TO INDIVIDUAL PERFORMANCE
- UTILIZE ADVANCED GRAPHICS
- PROVIDE UNIFORM AND VERIFIABLE TRAINING TO ENHANCE SAFETY
- ARE EASILY MAINTAINED

KEY CONTACTS:

JSC: ROBERT T. (BOB) SAVELY
FRANK HUGHES

KSC: TOM DAVIS
ASTRID HEARD

MSFC: MICHELLE PERRIN

GSFC: WALT TRUSZKOWKSI

HQ: GREGG SWIETEK
CHUCK HOLLIMAN

MAJOR MILESTONES (1990-1995):

1990: GENERAL ARCHITECTURE FOR ICAT SYSTEMS

1991: INTERFACE DEV. TOOLS

1992: KNOWLEDGE ACQUISITION TOOLS

1993: TOOL INTEGRATION

1994: TESTING AND DELIVERY OF GENERAL-PURPOSE ICAT DEV. ENVIRONMENT

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
OPERATIONAL EFFICIENCY
ADVANCED TRAINING SYSTEMS

NOVEMBER 1989

TECHNOLOGY ISSUES:

- AUTOMATION OF KNOWLEDGE ACQUISITION PROCESS
- HARDWARE FOR IN-FLIGHT ICAT SYSTEMS
- INTEGRATION WITH EXISTING SIMULATION SYSTEMS

CANDIDATE PROGRAMS:

CURRENT ICAT PROJECTS:

- FLIGHT CONTROL (JSC)
- SHUTTLE TESTING (KSC)
- SPACELAB SYSTEMS (MSFC)
- SATELLITE CONTROL (GSFC)
- IN-FLIGHT SYSTEMS (SHUTTLE AND SPACE STATION)

MAJOR ACCOMPLISHMENTS:

- OPERATIONAL ICAT SYSTEM FOR JSC FLIGHT CONTROLLERS
- TESTING WITH TRAINEE FLIGHT CONTROLLERS HAS SHOWN SIGNIFICANT IMPROVEMENTS IN TIME ON TASK WITH AN CONCURRENT DECREASE IN ERRORS
- ICAT SYSTEMS DELIVERABLE IN WORKSTATION ENVIRONMENTS

SIGNIFICANT MILESTONES:

- NASA AND UNIV. AI R&D PROVIDE TECHNOLOGY BASE FOR ICAT SYSTEMS
- CODE MD AND ST SUPPORT ICAT ARCHITECTURE AND DEV. ENVIRONMENT PROJECTS
- OPERATIONAL CENTERS SUPPORT SPECIFIC ICAT APPLICATION DEVELOPMENT

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
OPERATIONAL EFFICIENCY ADVANCED TRAINING SYSTEMS

NOVEMBER 1989

ADVANCED TRAINING SYSTEMS (ATS)

- EVOLVE IN CONTEXT OF STS UPGRADE STRATEGY
- STRATEGIC PLAN USES COMMERCIAL PRODUCTS, ADVANCED TECHNOLOGY, SSF COMPONENTS
- SELECT APPLICATIONS HAVE BEEN SUCCESSFULLY INTRODUCED AND DEVELOPED IN STS ONBOARD SPACE SYSTEMS
- SIGNIFICANT TECHNOLOGICAL ADVANCEMENT IN NEAR-TERM APPLICATIONS

MAJOR OBJECTIVES:

- LOW COST (DEVELOPMENT, IMPLEMENTATION)
- REUSE OF TRAINING MECHANISMS
  - ACROSS PROGRAM ELEMENTS
  - ACROSS PROGRAMS
- REDUCED SUPPORT INFRASTRUCTURE
  - DDT&E
  - OPERATIONAL
- SUPPORT FUTURE TECHNOLOGY UPGRADES
- SUPPORT UPGRADE AND TRANSFER OF SKILLS
- SUPPORT CAPTURE AND USE OF DDT&E INFORMATION IN THE OPERATIONS PHASE

KEY CONTACTS:

TONY MACINA	/IBM
ED CHEVERS	/JSC
ELRIC MCHENRY	/JSC
SAM ANKNEY	/JSC
JUDY N CHISWELL	/SEI

FACILITIES:

JSC SDF
IBM INTERNAL

FUTURE FACILITIES

JSC SPF
JSC SAIL
JSC TRAINERS
KSC LPS

MAJOR MILESTONES (1986 - 1992)

- REVIEW TECHNOLOGY (1986)
- BUILD PROTOTYPES, SELECTIVE USE TO DEMONSTRATE MATURITY (1987)
- INTRODUCE SUCCESSFUL APPROACHES INTO OPERATIONAL USE (1988)
- ESTABLISH STRATEGIC STS ADVANCED TRAINING PLAN (1989)
- RECONCILE PLAN WITH SSP STRATEGIC PLAN (1990)
- INTRODUCE JOINT PROTOTYPE INTO JSC LAB (1991)
- BEGIN INTRODUCTION INTO SUPPORT INFRA STRUCTURE (1992)

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
OPERATIONAL EFFICIENCY ADVANCED TRAINING SYSTEMS

NOVEMBER 1989

TECHNOLOGY ISSUES:

- TECHNOLOGY INTRODUCTION INTO STABLE OPERATIONAL ENVIRONMENT
- INTRODUCTION OF COMMON ARCHITECTURE INTO EXISTING DIVERSE SET
- CULTURAL AND ORGANIZATIONAL CHANGES OF EXISTING ENTITIES

CANDIDATE PROGRAMS:

STS

STS UPGRADE

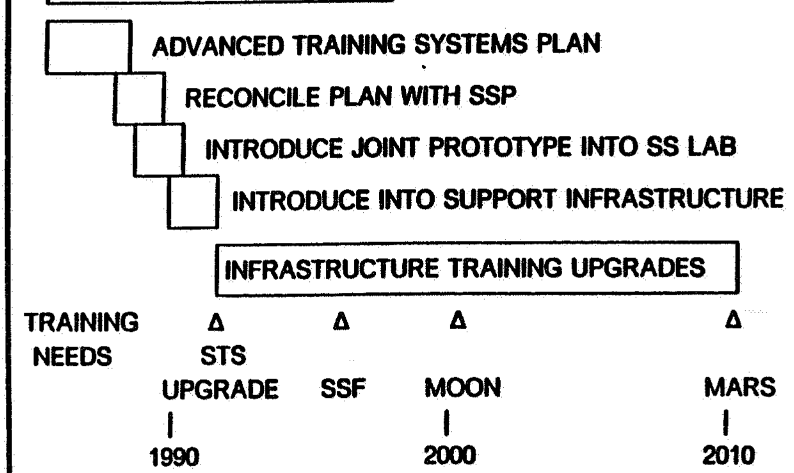
SPACE STATION PROGRAMS

SHUTTLE C

MAJOR ACCOMPLISHMENTS:

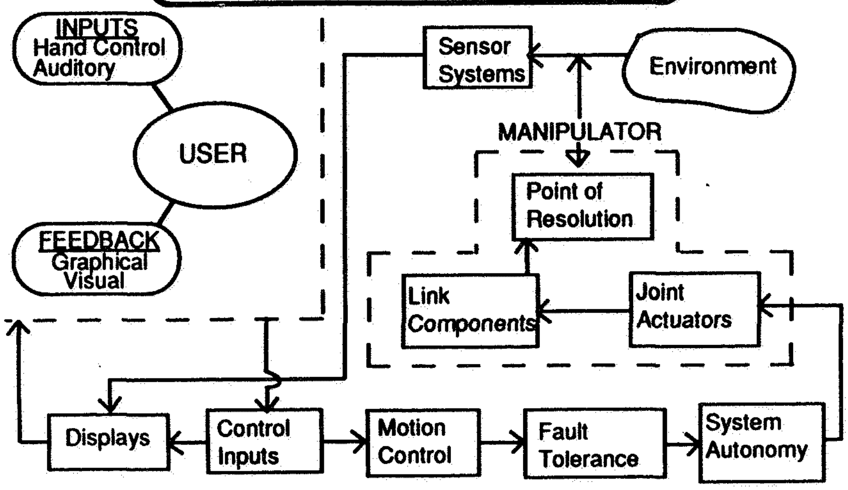
- TECHNOLOGY MATURITY DEMONSTRATED
- SUCCESSFUL ENTRY INTO SELECT OPERATIONAL AREAS
- CURRENT SSP APPROACHES APPEAR COMPATIBLE
- POTENTIAL FOR USE IN FOLLOW ON PROGRAMS (LUNAR BASE, MARS LANDING)

SIGNIFICANT MILESTONES:



SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
OPERATIONAL EFFICIENCY
TELEROBOTICS / TELEPRESENCE

TELEROBOTICS / TELEPRESENCE



MAJOR OBJECTIVES:

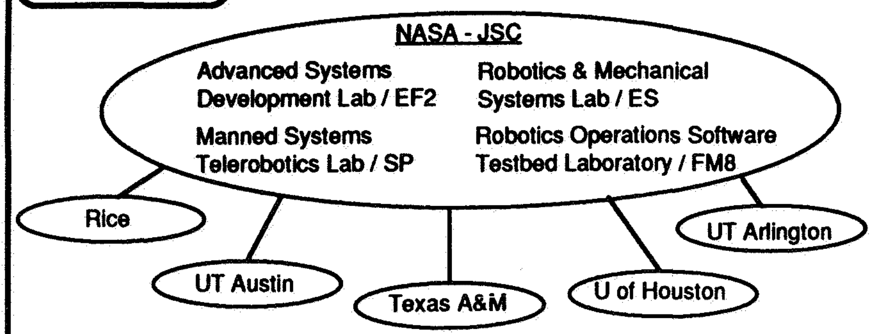
* Extend manned presence in space
  - Allow operations in locations not accessible by man
  - Provide for operations under hazardous conditions
  - Extend operations timelines by eliminating EVA restrictions
* Enable significant unmanned / autonomous operations
* Enhance crew safety
  - Minimize requirements for EVA
  - Reduce crew exposure to hazards
* Enhance crew time effectiveness
* Utilize current technology for prototype systems
* Provide capability to incorporate new technology as available
* Enhance commonality among in-flight, crew training, and engineering analysis systems

KEY CONTACTS:

C. Gott / FM8 — C. Price / EF2 — L. Stokes / ES

L. Quiocho / FM8 — J. LeGendre / SP

FACILITIES:



NASA / UNIVERSITY TELEROBOTICS LABORATORY NETWORK

MAJOR MILESTONES (1990 - 1995)

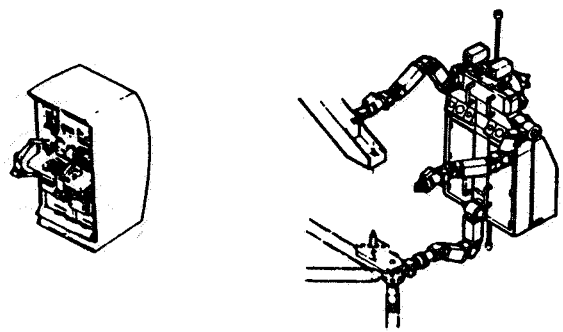
* Advanced RMS Control (1991)
* NASA / University Telerobotics Lab Network Demo (1992)
* SRMS Manipulator Controller Interface Unit (MCIU) Upgrade (1992)
* Fault Tolerant Manipulator Prototype Demo (1992)
* Dexterous Manipulator Demonstrations Flight Experiment (1992)
* Mobile Servicing Centre Flight Articles in JSC's Integrated Test Facility (SSAIAF) (1993)
* Fault Tolerant Manipulator Flight Hardware (1994)

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM

OPERATIONAL EFFICIENCY

TELEROBOTICS/TELEPRESENCE (FTS) NOVEMBER 1989

ADVANCED AVIONICS CONCEPTS



MAJOR OBJECTIVES:

FLIGHT TELEROBOTICS SERVICER (FTS)

- TELEROBOTIC SYSTEM USED FOR ASSEMBLY, MAINTENANCE, SERVICING, AND INSPECTION
- USE ON NSTS, SPACE STATION, OMV
- SPACE STATION FTS PLANNED FOR INDEFINITE LIFETIME WITH PERIODIC SERVICING AND UPGRADE

KEY CONTACTS:

H. MCCAIN/GSFC
K. HALTERMAN/GSFC
J. LOWRIE/MMC
J. DAVIDSON/MMC

FACILITIES:

GSFC ROBOTICS LAB
MARTIN MARIETTA FACILITIES, DENVER, COLORADO

MAJOR MILESTONES (1990 - 1995):

FTS MISSIONS

- NSTS DEVELOPMENT TEST FLIGHT-1 - 1991
- NSTS DEMONSTRATION TEST FLIGHT-2 - 1993
- SPACE STATION FIRST ELEMENT LAUNCH - 1995

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM

OPERATIONAL EFFICIENCY

TELEROBOTICS/TELEPRESENCE (FTS)

NOVEMBER 1989

TECHNOLOGY ISSUES:

- EVOLUTION OF OPERATIONAL TELEROBOT INTO AUTONOMOUS ROBOT
- INCORPORATE NEW TECHNOLOGIES AS THEY BECOME MATURE

CANDIDATE PROGRAMS:

- COMPUTER THROUGHPUT
- ALGORITHM DEVELOPMENT
- SENSORS
- VISION PROCESSING
- PATH PLANNING
- MODELS

MAJOR ACCOMPLISHMENTS:

- SELECTION OF NASREM FUNCTIONAL ARCHITECTURE
- RELEASE OF FTS EVOLUTION PLAN APRIL 1989
- EXECUTION OF FTS PRIME CONTRACT WITH MARTIN MARIETTA, JULY 1989

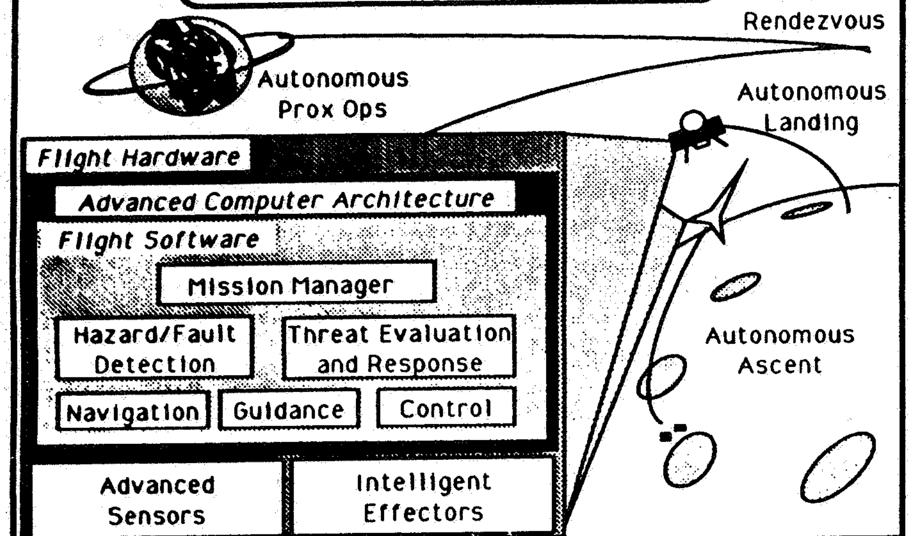
SIGNIFICANT MILESTONES:

- SHORT TERM EVOLUTION (< 5 YEARS) IMPROVE TELEPRESENCE
- LONG TERM EVOLUTION (> 5 YEARS) AUTONOMY

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
OPERATIONAL EFFICIENCY
AUTONOMOUS SPACECRAFT CONTROL

November 1989

ADVANCED AVIONICS CONCEPTS



MAJOR OBJECTIVES:

- Increase spacecraft autonomy
  - Reduce dependence on ground systems
  - Enable remote operations
- Reduce cost of spacecraft operations
  - Improve hardware/software commonality and modularity
  - Improve propellant efficiency
- Improve spacecraft reliability and mission readiness
  - Autonomous planning for time-limited missions
  - Reduce crew workload
- Enhance mission success probabilities and performance
  - Improve capability to survive on-board failures
  - Provide for task adaptation based on unanticipated changes in operating environment
  - Increase maneuver accuracy
  - Reduce plume impingement/contamination
- Reduce development risk

KEY CONTACTS:

K. Baker/JSC - Autonomous Landing
C. Gott/JSC - Autonomous Rendezvous
R. Kahl/JSC - MRSR Study
S. Lamkin/JSC - Pathfinder AR&D
J. Lamoreux/JSC - AR&D and Landing Sensors
J. Moore/JSC - Satellite Servicer System
R. Savely/JSC - Artificial Intelligence

FACILITIES:

- JSC Integrated Graphics Operations Assessment Laboratory (IGOAL)
- JSC Autonomous Operations Testbed (AUTOPS)
- JSC Tracking Test Bed / 6-DOF Positioner
- JSC Manipulator Development Facility
- JSC & MSFC Air Bearing Floor Facilities
- JSC Hybrid Vision Laboratory

MAJOR MILESTONES (1990 - 1996)

- Review technologies (1989-1990)
- Develop most critical and beneficial technologies and techniques (1990-1993)
- Demonstrate autonomous rendezvous, docking and proximity operations (1993-1994)
- Ground/atmospheric flight demonstration of autonomous landing and hazard avoidance sensors/processor technologies and techniques (1994-1996)

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
OPERATIONAL EFFICIENCY
AUTONOMOUS SPACECRAFT CONTROL

November 1989

TECHNOLOGY ISSUES:

- Degree of autonomy
  - Sensing and perception
  - Intelligent control
  - Supervised actuation
  - Task planning and management
- Role of artificial intelligence (AI) technology
- Tracking/Vision sensing techniques and Systems for AR&D and L
  - Navigation
  - Debris Avoidance
- Interactions with ground and manned systems
  - Command and control
  - Effects of communications time-lag
- System architecture and integration
  - Distributed computing and parallel processing
  - Cooperating expert systems
  - Location of sensor data processing
- System performance and reliability

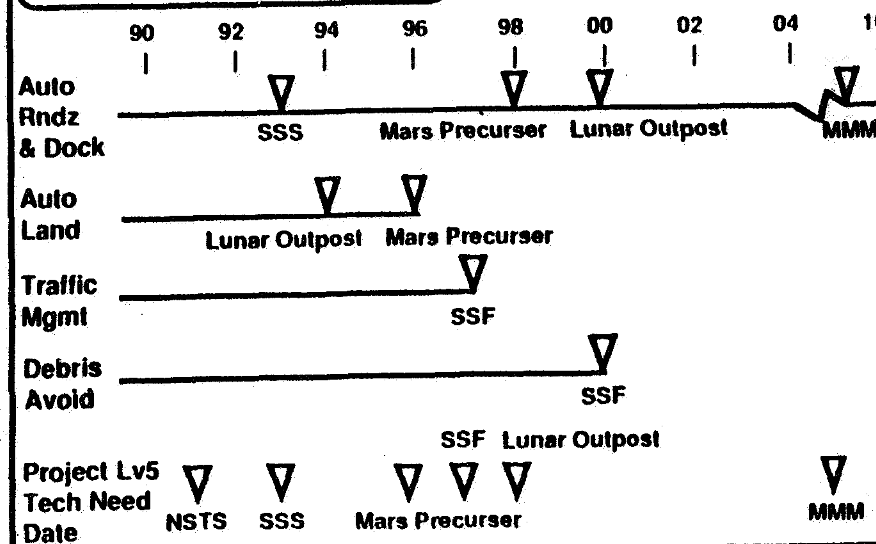
CANDIDATE PROGRAMS:

- NSTS
- Space Station Freedom (SSF)
- Satellite Servicer System (SSS)
- Crew Emergency Return Vehicle
- Heavy Lift Cargo Delivery Systems
- Orbital Maneuvering Vehicle (OMV)
- Orbital Transfer Vehicle (OTV)
- Aero-assist Orbital Transfer Vehicle (AOTV)
- Autonomous Free-Flyers
- Mars Rover/Sample Return
- Manned Lunar Base
- Manned Mars Mission (MMM)

MAJOR ACCOMPLISHMENTS:

- Autonomous Operations (AUTOPS) testbed development
- On-orbit operations knowledge capture
- Technology investigations in improved on-orbit algorithms and system and environment model
- Ladar being developed for SSS flight demonstration
- 3D Range/Doppler imager and processor in development
- Hybrid image processing in development
- Pathfinder technology studies in progress
- Definition of radio tracking navigation from lander to orbiter for accurate landing

SIGNIFICANT MILESTONES:



SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
OPERATIONAL EFFICIENCY
AUTONOMOUS SPACE CRAFT CONTROL

ADVANCED AVIONICS CONCEPTS

Tracking & Guidance Sensor with active Illumination	RMS Docking Target Augmented with retro-reflective material

MAJOR OBJECTIVES:

- Low cost
- Low complexity
- Requires only a passive target
- Capable of operating in a variety of scenarios

KEY CONTACTS

E.C. Smith/MSFC

F. Dabney/MSFC

R. Howard/MSFC

S. Lamkin/JSC

FACILITIES

MSFC Flight Robotics Laboratory

MAJOR MILESTONES (1990-1995):

- Test current technology (1990)
- Complete development of advanced applications (1991)
- Analysis and large scale hardware demonstration (1991)

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
OPERATIONAL EFFICIENCY
AUTONOMOUS SPACE CRAFT CONTROL

TECHNOLOGY ISSUES:

- Sensor range: moving parts vs. reliability
- Self-monitoring system to defect malfunctions

CANDIDATE PROGRAM:

- OMV
- Shuttle C
- Space Station
- MARS Rover-Sample Return
- Satellite Servicing

MAJOR ACCOMPLISHMENTS:

Software simulations of various docking/Berthing algorithms

Integrated large-scale hardware tests of system

Advanced algorithms developed and awaiting hardware testing

SIGNIFICANT MILESTONES:

CCD Sensor Development

System Integration & Testing

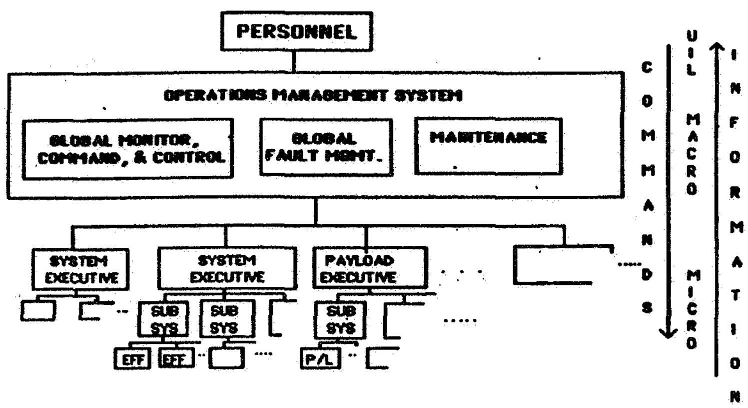
Advanced Development

OMV SSS LUNAR/MARS

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
OPERATIONAL EFFICIENCY
OPERATIONS MANAGEMENT SYSTEM

NOVEMBER 1989

INTEGRATED COMMAND & CONTROL



MAJOR OBJECTIVES:

PROVIDE INTEGRATED ONBOARD COMMAND & CONTROL OF VEHICLE SYSTEMS.

USE AUTOMATED SYSTEMS TO REDUCE CREW WORK LOAD.

USE STANDARDIZED PROCEDURES TO REDUCE OPERATIONAL COMPLEXITY.

PROVIDE INTER-VEHICLE OPERABILITY BY USE OF COMMON COMMAND & CONTROL SOFTWARE.

REDUCE SE&I COMPLEXITIES BY USE OF STANDARDIZED HIERARCHICAL SOFTWARE STRUCTURES.

BUILD COMMAND & CONTROL SYSTEMS THAT CAN EVOLVE.

KEY CONTACTS:

A. BRANDLI / JSC / EH3
R. ECKELKAMP / JSC / FM4
D. OWENS / JSC / DS2
P. HARTLEY / GSFC / 512
L. HENSCHEN / MCDONNELL DOUGLAS
C. KELLY / MITRE
D. RUE / TRW
W. MCCANDLESS / LESC

FACILITIES :

OMS TESTBED
PMS TESTBED
VARIOUS CONTRACTOR TESTBEDS

MAJOR MILESTONES (OMS PROTOTYPES)

CONCEPTUAL STUDIES ('85 - 86')

STANDALONE PROTOTYPES ('86 - '87)
LISP, SYMBOLICS, 1ST DEMO 10-86

OMS INTEGRATED IN TESTBED PHASE 1 ('87 - '88)
WITH GN&C EMULATOR TEST BED FOR REBOOST, DEMO 1-88

OMS INTEGRATED IN TESTBED PHASE 2 ('89 - '90)
ADA, C ON MICROVAX, SUN WITH GN&C, TCS, C&T, GEPDC, MPAC

ADDITIONAL OMS FUNCTIONS & NODES ('89 - '91)
STATION SHORT TERM PLAN, REPLANNING, PAYLOADS

MULTIPLE VEHICLE OMS ('91 - '93)

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OF POOR QUALITY

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
OPERATIONAL EFFICIENCY
OPERATIONS MANAGEMENT SYSTEM

NOVEMBER 1989

TECHNOLOGY ISSUES:

RELIABLE EXPERT SYSTEMS FOR COMMAND & CONTROL

SOFTWARE CAPABLE OF BEING TRANSFERRED AMONG SPACE PROGRAMS (E.G., PARTS LIBRARY, APPLICATIONS GENERATOR)

PERFORMANCE OF MAINTENANCE CONCURRENT WITH OPERATIONS

FLEXIBLE COMPUTER SYSTEMS ALLOWING TECHNOLOGY UPGRADES & MULTIPLE LANGUAGES

ADVANCES IN SOFTWARE ENGINEERING METHODOLOGIES & IN OPTIMIZATION OF SOFTWARE STRUCTURES

ADVANCED MAN-MACHINE COMMAND & CONTROL INTERFACES

CANDIDATE PROGRAMS:

CERV INCLUDING AUTOMATED ENTRY
STATION OMS
LUNAR / MARS INITIATIVE
MARS SAMPLE RETURN MISSION
NEXT GENERATION SHUTTLE
NATIONAL AEROSPACE PLANE
ADVANCED INTERPLANETARY PROBES
POTENTIAL RETROFIT FOR NSTS GROUND
MAINTENANCE
GLOBAL FAULT MANAGEMENT

MAJOR ACCOMPLISHMENTS:

HIERARCHIAL COMMAND & CONTROL ILLUSTATED IN OMS TESTBED

MULTIPLE PROTOTYPES IN GLOBAL FAULT MANAGEMENT

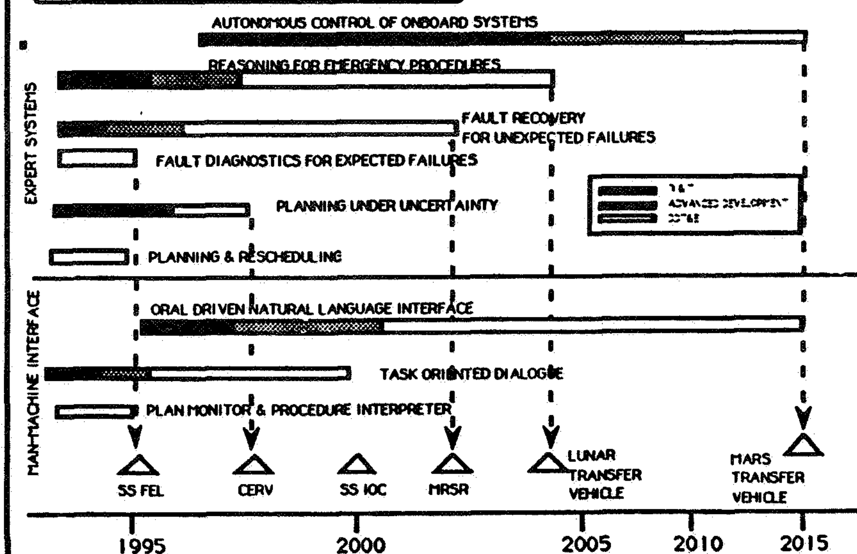
EXPERT PLAN GENERATORS

PROTOTYPES IN PLAN EXECUTION, MONITORING, & REPLANNING

MAINTENANCE PROTOTYPE BEING TESTED IN NSTS CONTROL CENTER

OPERATIONAL REALTIME SYSTEM MONITORS ("INCO" AT JSC & "SHARP "AT JPL)

SIGNIFICANT MILESTONES:



SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
OPERATIONAL EFFICIENCY
ADVANCED TEST AND CHECKOUT SYSTEMS

NOV 1989, rev E

ADVANCED AVIONICS CHECKOUT CONCEPTS

TEST & CHECKOUT CAPABILITIES INCORPORATED IN BASIC SYSTEM ARCHITECTURE

AUTOMATIC, AUTONOMOUS TESTING
- ADVISORY DATA ONLY TO GROUND
- GROUND CONTROL OF INITIATION, MONITORING & SAFING

LIFE CYCLE COSTS DRIVE TECHNOLOGY SELECTION
- PROCESSORS, MODULAR SOFTWARE, MEMORIES

FAULT ISOLATION TO FAILED BOX OR CARD
- EXTENSIVE "BITE", EASY REPLACEMENT
- SMART SENSORS/EMBEDDED PROCESSORS
- EXPERT SYSTEM DIAGNOSTICS
- GO/NO-GO HEALTH STATUS REPORTING

BOTH IN-FLIGHT AND GROUND TESTING
- SYSTEM-LEVEL "END-TO-END" SELF TEST
- INDEPENDENT SUBSYSTEM VERIFICATION TESTING
- REDUNDANCY VERIFICATION AND TREND ANALYSIS

MAJOR OBJECTIVES:

REDUCE COST OF GROUND TEST AND CHECKOUT
- $, PERSONNEL, TIME

INCREASED AUTOMATION OF TEST AND CHECKOUT

INCREASED TESTABILITY OF SUBSYSTEMS AND LRU'S

ON-ORBIT DIAGNOSTICS AND READINESS VERIFICATION

APPLY TEST & CHECKOUT REQTS AT SYSTEM LEVEL
- AT START OF PROGRAM

KEY CONTACTS:

CHARLES TEIXEIRA, NASA/JSC

DON BROWN, NASA/JSC

CAREY MC CLESKEY, NASA/KSC

LEE SHOCKLEY, ROCKWELL/STSD

DICK THIEL, ROCKWELL/STSD

JIM TULLEY, LSOC/KSC

FACILITIES:

NASA & CONTRACTOR LAB FACILITIES
SUCH AS:
- JSC AVIONICS ENGINEERING LAB (JAEL)

MAJOR MILESTONES:

PROPOSED SHUTTLE EVOLUTION CHANGES ENHANCE T&C/O
- GLASS COCKPIT
- EMA
- INSTRUMENTATION UPGRADE

RAPIDLY ADVANCING EXPERT SYSTEM SOFTWARE

APPLICATION OF MIL SPECS ON TESTABILITY/BITE
- INCORPORATED IN MODERN BOXES/CARDS

AIRLINE & AIRFORCE IMPLEMENTATION OF ONBOARD TEST

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
OPERATIONAL EFFICIENCY
ADVANCED TEST AND CHECKOUT SYSTEMS

NOV. 1989, rev E

TECHNOLOGY ISSUES:

ONBOARD VERSUS GROUND TRADES
- MANNED VS UNMANNED, EXPENDABLE VS REUSABLE

LIFE CYCLE COST ISSUES/TRADES
- GROWTH PROVISIONS & STANDARDIZATION
- LAUNCH WITH FAILURE
- COST OF BITE VS OPERATIONAL SAVINGS
- ACCESSIBILITY

SOFTWARE APPLICATION TRADES
- SOFTWARE CHANGE VERIFICATION ONBOARD
- EXPERT SYSTEMS, TRENDING, KNOWLEDGE CAPTURE

AVIONICS SYSTEM TRADES
- CENTRAL VS DISTRIBUTED PROCESSING
- SOFTWARE VS FIRMWARE
- LANGUAGE SELECTION

DATA STORAGE DEVICES
- OPTICAL DISK, BUBBLE MEMORY, MAGNETIC TAPE

CANDIDATE PROGRAMS:

SHUTTLE EVOLUTION
- EVALUATE FOR ALL PROPOSED SUBSYSTEM UPGRADES

ACRV (ASSURED CREW RETURN) (CERV)
- AUTOMATIC ONBOARD T&C/O WILL BE MANDATORY

SHUTTLE C
- LOW OPERATIONAL COST REQUIRES ADVANCED T&C/O

LAUNCH PROCESSING SYSTEM UPGRADE
- LPS UPGRADES SHOULD CONSIDER PLANNED VEHICLE TESTABILITY IMPROVEMENTS, AND VICE-VERSA

AMLS (ADVANCED MANNED LAUNCH SYSTEM)

PLS (PERSONNEL LAUNCH SYSTEM)

NASP (NATIONAL AERO SPACE PLANE)

MAJOR ACCOMPLISHMENTS

CONTINUING EVOLUTION OF ELECTRONICS EXPANDS AVAILABLE SOLUTIONS
- ONBOARD COMPUTATIONAL AND MEMORY CAPABILITIES ARE REALIZABLE
- OPTICAL BUSES & MEMORIES PROVIDE CAPABILITY TO HANDLE LARGE DATA BASES

GOVERNMENT SPONSORED PROGRAMS SUPPORT BITE, MODULARITY AND DISTRIBUTED PROCESSING
- MISSION CONTINUATION WITH FAILURES (ROBUSTNESS)
- ACCESSIBILITY (RACK MOUNTED CARDS/BACK PLANE)

ARTIFICIAL INTELLIGENCE (AI) APPLICATIONS CONTINUE TO EXPAND
- SUPPORTS ONBOARD DIAGNOSTIC DEVELOPMENT

SIGNIFICANT MILESTONES:

TEST & CHECKOUT SOFTWARE VERIFICATION AND MAINTAINANCE COST CONTAINMENT METHODOLOGY

DEVELOP REALISTIC LIFE-CYCLE COST ANALYSIS TECHNIQUE

FURTHER DEVELOPMENT OF AI FOR COMPLEX SYSTEMS

INVESTIGATION OF PACKAGING TECHNIQUES FOR RAPID ACCESS FOR R&R

C-4

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
OPERATIONAL EFFICIENCY
ADVANCED MISSION CONTROL

TECHNOLOGY CONCEPT:

- Intelligent Assistance for Ground-Based Mission Controllers and Space-Based Crew
- Autonomous Onboard Monitoring, Control, and FDIR
- Dynamic Corporate Memory Acquired, Maintained, and Utilized During Entire Vehicle Life-Cycle

MAJOR OBJECTIVES:

- Reduced Manpower Needs
- Reduced Training Time
- Improved Critical Decision-Making
- Enhanced Mission Safety by Discovery of Incipient Failures
- Free Crew to Conduct Mission Tasks
- Provide Realtime Capabilities Beyond Human Performance Levels
- Capture Knowledge Throughout Design, Construction, Test, and Operations
- Provide Focused Problem-Solving Capability

KEY CONTACTS:

P. Friedland/ARC
J. Muratore/JSC
A. Heard/KSC
D. Atkinson/JPL
M. Montermerlo/HQ-RC
G. Swietek/HQ-ST
C. Holliman/HQ-MD
S. Cross/DARPA
M. Benda/Boeing
C. Hall/Lockheed

KEY FACILITIES:

ARC Laboratory-ASRF
JPL Laboratory

MAJOR MILESTONES:

- Review Experience in Launch and Mission Control Automation at JSC, KSC, and JPL. Determine Major Areas of Technology Integration and Improvement (1990).
- Demonstrate Techniques on SSF testbeds and on STS non-mission-critical experiments (1991-1993).
- Determine Technology Utilization Plan for Lunar/Mars Exploration Missions (1990-1995).

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
OPERATIONAL EFFICIENCY
ADVANCED MISSION CONTROL

TECHNOLOGY ISSUES:

- Correct Mix of Humans and Machines for Decision Support
- Integration of Artificial Intelligence and Advanced Interaction Concepts (Hypermedia, Direct Interaction Devices, Multi-Media, etc.)
- Hardware and Software Environments for Realtime Onboard Behavior
- Data Storage and Realtime Access for Very Large-Scale Corporate Memory Systems
- Knowledge Acquisition and Maintenance during Long-Term Missions
- Qualitative Reasoning about Complex Systems

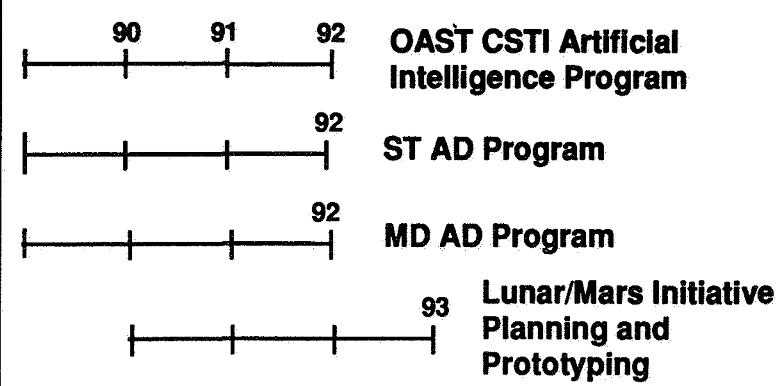
CANDIDATE PROGRAMS:

- SSFP (Onboard, TMIS, and SSCC)
- ALS
- NSTS
- Lunar/Mars Missions

MAJOR ACCOMPLISHMENTS:

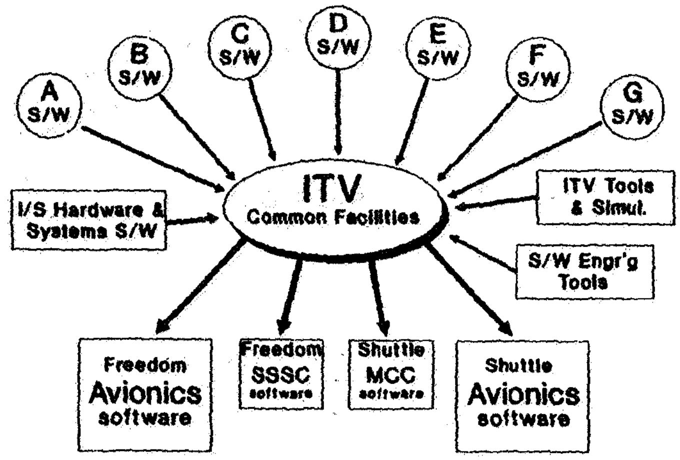
- Use of Advanced Automation in MCC at JSC and During Voyager Neptune Flyby at JPL
- World-Class Laboratories at ARC and JPL
- SSF Advanced Development Program Tasks
- Full Integration with DARPA and AF Programs

SIGNIFICANT MILESTONES:



Advanced Software Integration

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
ADVANCED SOFTWARE INTEGRATION



stats01-jrp1031

Major Objectives

- Maintaining reliability in increasingly complex software and information systems (contrasts in STS and SSFP avionics).
- Enabling evolution (functionality, technology, connectiveness) in systems which are now "never-ending".
- Managing increasingly distributed work-packets and efforts in the development of applications software for the advanced systems.
- Reuse and commonality (across systems and programs) both an operations efficiency (training, management, etc.) and as a productivity item.

stats02-jrp1031

Key Contacts & Facilities

Contacts:
- John R. Garman/JSC(FA)
- Ed Chevera/JSC(FR)
- Rick Coblentz/JSC(FR)
- Jack Seyl/JSC(FS)
- Charles McKay/UHCL (JSC)

Facilities:
- Information Systems Technology Lab (ISTL)/JSC(FA)
- Avionics Development Lab (SSFP/WP2)/JSC(FR)
- Software Development Facility (NSTS)/JSC(FR)
- Support Software Environment Development Facility (SSEDF)/JSC(FR)
- Mission Systems ITV Facility/JSC(FS)

Major Milestones (1990-1995)

- Operation of STS SAIL and SPF (1976)
- SSE Baseline for SSFP (1990)
- Avionics Integration and ITV baseline for SSFP (1990)
- Mission Systems ITV (MSITV) Facility Design (1990)
- ADF and MSITV FOC (1992)
- Shuttle and SSFP ITV commonality (1997)

Advanced Software Integration (cont'd)

Technology Issues

- Containment of growing drivers: complexity, connectivity, security, and architectures
- Standardization of I/S "layers" - Industry standards
- Virtual target environments (exact simulation of target platform allowing diagnostics)
- "Project Object Database" - the database and management technologies involved in creating a single unambiguous image of the entire distributed software system
- Integration of heterogenous products designed against common standards (both the host and target domains)
- Software Lifecycles modeled against evolutionary development and maintenance (vs. waterfall)

stats05-jrg1101

Candidate Programs

- NSTS Avionics Flight Software
- NSTS Mission Control Center Upgrade
- NSTS Other I/S
- *SSFP Data Management System (avionics)*
- SSFP Mission Control and Trainers
- SSFP Other I/S
- Advanced Programs (Lunar/Mars)

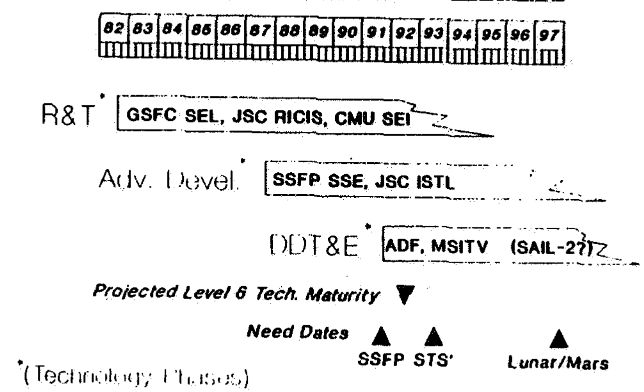
stats06-jrg1031

Major Accomplishments/"Inabilities"

✓ Major Accomplishments
- Establishment of RICIS
- Establishment of SSE development effort
- Baselining of commonality in applications tools *and UI for SSFP*
- Industry evolution toward standardization of I/S layers

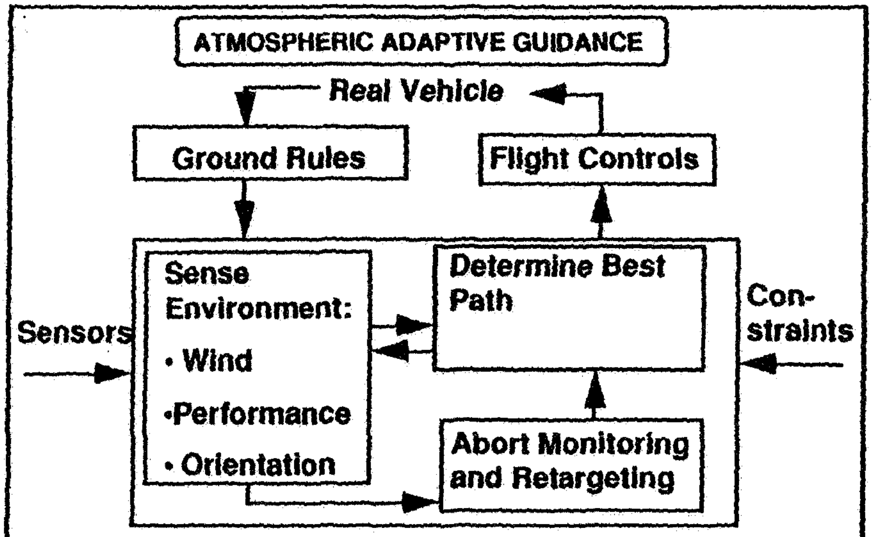
✓ Major "Inabilities"
- Duplication of effort across Programs/Projects
- Proliferation of mission supporting software
- Inability to fully utilize COTS
- Inability to upgrade existing capabilities

SIGNIFICANT MILESTONES
Advanced Software Integration



SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
OPERATIONAL EFFICIENCY
ATMOSPHERIC ADAPTIVE GUIDANCE

NOVEMBER 1989



MAJOR OBJECTIVES:

- Improve Safety Margins
- Reduce Costs/Time Associated with Pre-Launch Planning
- Improve Vehicle Performance and Increase Launch Probability
- Minimize Required DOL Ground Support
- Increase Weather Envelope

KEY CONTACTS:

- Douglas Price/LaRC
- David Long/JSC
- Daniel Moerder/LaRC
- David Geller/JSC

MAJOR MILESTONES (1990-1995):

- Algorithm Feasibility Investigation (1989)
- DOL I-Load Update Implementation (1990)
- Advanced Wind Measurement System (1992)
- Onboard Algorithm Dev. (1992)
- Advanced Flight/Space Rated Computers (1994)

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
OPERATIONAL EFFICIENCY
ATMOSPHERIC ADAPTIVE GUIDANCE

NOVEMBER 1989

TECHNOLOGY ISSUES:

- Partitioning of Guidance Between Ground and Vehicle
- Onboard Guidance/Control Algorithm Sophistication
- Wind Knowledge Required
- Onboard Sensor Capabilities
- Computational Capability Required

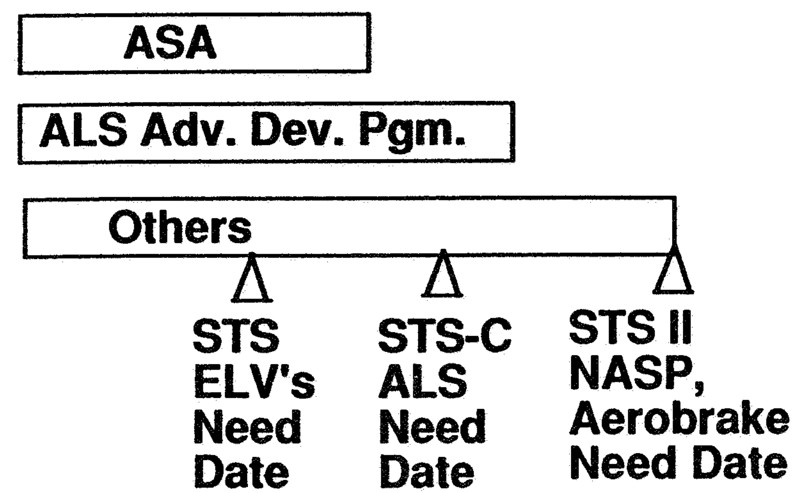
CANDIDATE PROGRAMS:

- Assured Shutle Availability (ASA)
- Shuttle-C
- Advanced Launch System (ALS)
- ELV's
- Shuttle II
- Lunar/Mars Missions (Aerobrake)
- NASP

MAJOR ACCOMPLISHMENTS:

- STS Alternate I-Loads Capability
- STS Adaptive Guidance Throttling
- ALS Onboard LIDAR Wind Mapper/Adaptive Trajectory Sampling Feasibility & Benefit Study
- KSC Statistical Wind Simulation Model for Synthesizing Launch Wind Profiles

SIGNIFICANT MILESTONES:



SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMNPOSIUM
OPERATIONAL EFFICIENCY

Health Status and Monitoring

ADVANCED HS&M CONCEPTS

- PAPERLESS LIQUID ROCKET ENGINE HISTORY ANDMAINTENANCE PROCEDURES
- MAINTENANCE ON DEMAND
- INTEGRATED VEHICLE HEALTH MANAGEMENT WITH ROCKET ENGINE HEALTH MONITORING
- UTILIZE ON BOARD HS&M CAPABILITIES FOR GROUND TEST
- MINIMIZE GSE

MAJOR OBJECTIVES:

- PROVIDE VISIBILITY INTO SYSTEM READINESS
- REDUCE COST OF PRE-FLIGHT CHECKOUT AND POST-FLIGHT MAINTENANCE
- INCREASE PROBABILITY OF MISSION SUCCESS

ADVANCED HS&M CONTACTS

AEROJET	- CARRIE KOECHEL
ROCKETDYNE	- ARNIE NORMAN
PRATT & WHITNEY	- JOSEPH BAKER
ASTRONAUTICS LAB	- ROBERT VACEK
NASA LeRC	- LARRY COOPER
NASA MSFC	- W.T POWERSEL
NASA JSC	- T. BARRY
IBM	- L. SMALL
HARRIS	- R. MONIS
BOEING	- JEFF ALBERT
GENARAL DYNAMICS	- JOSEPH JOHNSON
MARTIN MARIETTA	- RON PUENING

MAJOR OBJECTIVES:

- SSME SAFETY MANAGEMENT –1994 (OPEN LOOP ENGINE TEST)
- SPACE TRANSPORTATION ENGINE PROGRAM
  - DESIGN CONCEPT REVIEW 3/90
  - MIDTERM DEFINITION REVIEW 1/91
  - FINAL PROJECT REVIEW 9/92
- ALS INITIAL LAUNCH CAPABILITY 1998

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMNPOSIUM
OPERATIONAL EFFICIENCY

Health Status and Monitoring

TECHNOLOGY ISSUES:

- SENSOR DEVELOPMENT
- SENSOR/COMPUTER INTERCONNECT DEVELOPMENT
- COMPUTER I/O (MODULARITY)
- GENERIC HEALTH MONITORING ARCHITECTURE
- HEALTH MONITOR/SYSTEM INTEGRATION & SIMULATION (GROUND AND ON BOARD)
- ALGORITHM/SOFTWARE DEVELOPMENT
- DATA PROCESSING
- VEHICLE AVIONICS COMMONALITY

MAJOR ACCOMPLISHMENTS:

- NASA LeRC
  - ROCKET ENGINE LIFE PREDICTION AND MODELING
  - REUSABLE ROCKET ENGINE DIAGNOSTIC SYSTEM DESIGN
  - ADVANCED MASS STORAGE
  - REUSABLE ROCKET ENGINE TRUBOPUMP HEALTH MANAGEMENT SYSTEM
- NASA
  - MSFC/SSME HEALTH MANAGEMENT
  - JSC/SPACE STATION
- USAF – (AL)
  - ROCKET ENGINE CONDITION MONITORING
  - VEHICLE HEALTH MONITORING SYSTEM

CANDIDATE PROGRAMS:

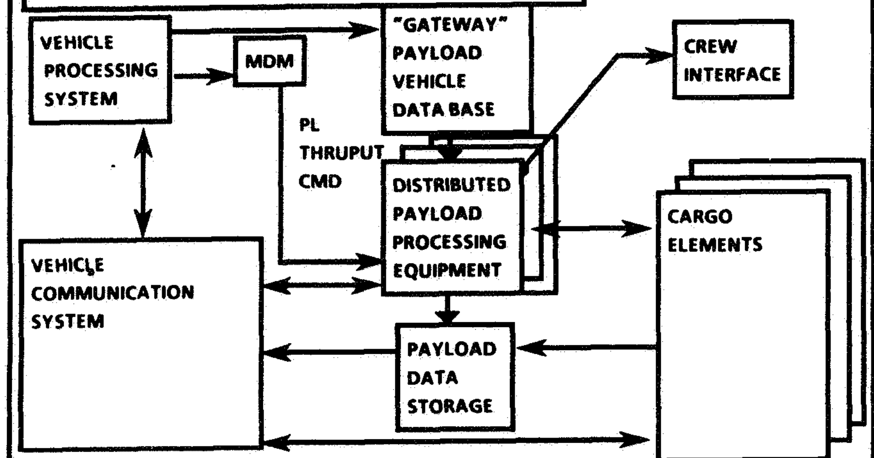
- SPACE TRANSPORTATION ENGINE PROGRAM
- ADVANCED LAUNCH SYSTEM PROGRAM
- PATHFINDER PROGRAM
- EARTH–TO–ORBIT
- NASP
- NSTS UPGRADES
- LUNAR/MARS EXPLORATION INITIATIVES
- CERV

SIGNIFICANT MILESTONES:

- ESTABLISH & MAINTAIN FUNDING
- SPACE STATION PDR - 1990
- VERIFY ENGINE / SENSOR FAILURE DETECTION - 1990
- DEMONSTRATE ALS HEALTH MONITORING TECHNOLOGIES - 1993
- EXPERT SYSTEMS (LIFE PREDICTION) - 1993

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
PAYLOAD ACCOMMODATIONS
AVIONICS PAYLOAD SUPPORT ARCHITECTURE

AVIONICS PAYLOAD SUPPORT ARCHITECTURE



MAJOR OBJECTIVES:

- RELIABLY PROVIDE SERVICES TO PAYLOAD CUSTOMERS TO MEET THE EXPECTED REQUIREMENTS (EXPANDED COMMAND, TELEMETRY, VIDEO SERVICES, ONBOARD DATA STORAGE CAPABILITY, "GATEWAY" TO VEHICLE DATA)
- REDUCE LABOR INTENSIVE INTEGRATION/RECONFIGURATION/OPERATIONS/TRAINING
- REDUCE INTERDEPENDENCE OF VEHICLE AND PAYLOAD
- PAYLOAD SERVICES ARCHITECTURE SHOULD UTILIZE GOVERNMENT/INDUSTRY STANDARDS, E.G., 80386 PROCESSOR, 1750A PROCESSOR, 1553 DATA BUS, ETC.
- PROVIDE PROGRAM INTERCHANGEABILITY OF COMPONENTS AND CAPABILITY TO EASILY UPGRADE SYSTEM AS NEW CAPABILITIES ARE DEVELOPED.

KEY CONTACTS:

STAN BLACKMER/JSC/TJ (STS)
BILL MALLARY/JSC/EH (SSF)
NED TRAHAN/JSC/EH
C. D. LEVY/MMC
S. L. CREASY/JSC/DH6

MAJOR MILESTONES:

- PROVISION FOR USE OF PAYLOAD AND GENERAL SUPPORT COMPUTER (GRID 1530) FOR PAYLOADS ON THE STS
  - ICD, USER GUIDELINES-1989
  - FEA, PM-1989
  - USE WITH TSS-1991
  - NUMEROUS SECONDARY PAYLOADS FROM 1990 ON
- SSF PAYLOAD SUPPORT ARCHITECTURE DEFINITION/DESIGN
- SHUTTLE-C PAYLOAD SERVICES DEFINITION

517

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34P

PRESENTATION 2.2

N91-17030

FLIGHT ELEMENTS

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM

FLIGHT ELEMENTS SUBPANEL

INTRODUCTION & OVERVIEW

PAUL E. SOLLOCK NOVEMBER 7, 1989

FLIGHT ELEMENTS TOPICS

- ADVANCED AVIONICS SYSTEMS ARCHITECTURES

  Fault-tolerant distributed processing configurations

  Accomodate Growth and tailored functional reliability

- ADVANCED PROCESSORS

  Digital, symbolic and photonic technologies

  Increased capabilities for on-board autonomous operations

- INTEGRATED GPS/GN&C

  Autonomous navigation, alternative attitude determination

  Power, weight and performance enhancements

FLIGHT ELEMENTS TOPICS (cont.)

- ADVANCED DISPLAYS AND CONTROLS

  Improved flight safety and operational efficiency

  Commonality & flexibility for multiple program support

- ADVANCED COMMUNICATIONS AND TELEMETRY

  Maximize data rate with very low power consumption

  Fiber Optics and Gallium Arsenide Technologies

- ADVANCED SENSORS AND INSTRUMENTATION

  Higher accuracies with local signal conditioning

  Self-calibrating and local data recording

FLIGHT ELEMENTS TOPICS (cont.)

- FAULT DETECTION AND FAULT MANAGEMENT

  Monitor, diagnose and reconfigure at all levels

  Blend with maintenance/operations functions

- ADVANCED ELECTRICAL POWER DISTRIBUTION & CONTROL

  Intelligent power switching and control devices

  Adaptable distribution architectures for varied users

- EMA POWER SYSTEMS

  Replace classical hydraulics for obvious benefits

  Electromagnetic Actuators and associated power systems

FLIGHT ELEMENTS TOPICS (cont.)

- IN-FLIGHT CREW TRAINING

  Maintain crew proficiency during long duration missions

  "Real-time" training for unplanned scenarios

FLIGHT ELEMENTS--PAST, PRESENT & FUTURE

- PAST PROGRAMS

  Relatively short lead times--pick a design and build it

  Utilized off-the-shelf components and tailored OR

  Built unique one-time hardware and software

  Relatively short duration missions

  Programs ended before technology reached obsolescence

- PRESENT TRENDS

  Becoming sensitive to effects of evolving technologies on long-duration programs and need for reduced costs

  Long-duration programs inevitably attract unforeseen new missions stretching capabilities of original avionics

  Commercial technology boom has created abundance of potential basic technologies for specific adaptations

FLIGHT ELEMENTS--PAST, PRESENT & FUTURE (cont.)

- FUTURE PROSPECTS

  Future programs will likely have longer periods for study, selection and maturation of technologies

  Challenge will be to *select* a technology which can be brought to maturation BUT not be *obsolete* before Phase C/D

  NASA must strive for commonality accross major programs to *reduce everyone's cost of ownership*--requires careful planning of upgrades to ongoing programs AND commitments *from* planned programs

  Potential users of new technologies; i.e., new programs or planned upgrades should "invest" in OAST programs to *focus* development programs toward specific products--Space Station Advanced Development Program (1984-86) was pathfinder.

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM

FLIGHT ELEMENTS

ADVANCED AVIONICS SYSTEMS ARCHITECTURES

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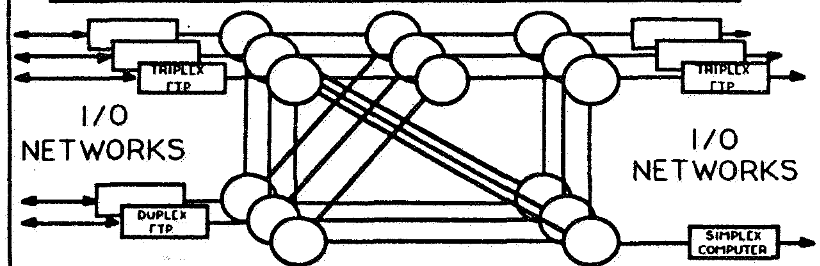
Advanced Information Processing System



Features:
- ADA Operating System
- Fault-Tolerant Distributed Processing Sites
- Fault-Tolerant Inter-computer Network
- Appropriate Function Reliability
- Low Fault Tolerance Overhead
- Growth Capability
- Redundancy Transparent to User

Major Goals and Objectives:

- Improved Reliability at Lower Cost
- Low Recurring Hardware and Operations Cost
- Enable/Support Launch-On-Demand
- Open-Ended Architectures that Support System Growth and Change
- Vehicle-Wide Standardization of Architectural Concepts
- Autonomous, Factory-To-Flight Subsystem Integrity and Confirmation
- Enable/Support Autonomous Long Duration/Distance Flight Operations
- Flexible/Secure Interfaces for Payload and Other Non-Avionic System Support
- Autonomous Pre-Flight System Support and Test

Key Contacts:

JSC- Tom Barry, Tom Morre	BAC - D. Johnson
LaRC - C. Meissner, F. Pitts	CSDL - J. Lala
LeRC - H. Wimmer	GD - J. Karas
MSFC - W. Chubb, W. Brantley	HI - J. Weyrauch
WDRC - J. Stanley, R. Bortner	RIC - L. Shockley
JPL - D. Rennels	MMC - R. Gates

Facilities

- -JSC Avionics Eng. Lab
- -MSFC Avionics Productivity Center
- -LaRC AIRLAB

Major Milestones (1990-1995):

TECHNOLOGY DEMO'S IN WORK:

- MPRAS
- Common Module Military Aircraft Flight Tests

RECOMMENDED DEMOS:

- Define System Goals and P31 Planning (90 and 91)
- Joint Lab Demo's at MSFC/JSC with FLT Test at Ames (92 and 93)
- Insertion on Combined STS and Shuttle-C Upgrades

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM

FLIGHT ELEMENTS

ADVANCED AVIONICS SYSTEMS ARCHITECTURES

NOVEMBER 1989

Technology Issues:

- Level of Fault Tolerance
- Cost vs. Reliability
- Utility of Building-Block Architectures
- Modeling/Test Mix for Validation
- Design for Launch-With-Failures
- EME-HARD Design and Assessment
- Software Development Environment
- ADA Software for High-Bandwidth Control

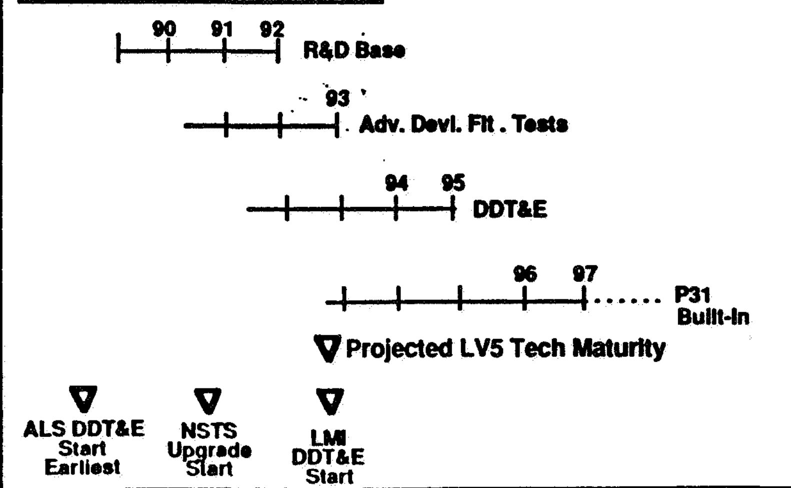
Candidate Programs:

- Assured Shuttle Availability, Unmanned Orbiter
- NASP, CERV
- Shuttle-C, ALS
- Existing Launch Vehicles
- SSP, Lunar Mars Initiative

Major Accomplishments:

- Space Station Avionics Design Captures Some Objectives
- ALS Requirements and Advanced Technology Development Meets/Exceeds Objectives
- Advanced Military Aircraft in DDT&E (A-12 and ATF) Captures Objectives and Developing Usable Hardware
- Commercial aircraft fault-tolerant / distributed systems

Significant Milestones:

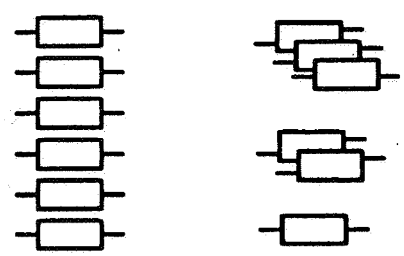


SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
FLIGHT ELEMENTS
ADVANCED AVIONICS ARCHITECTURE

NOVEMBER 1989

ADVANCED AVIONICS CONCEPTS

EXPLOIT THE POTENTIAL SYNERGISM BETWEEN PARALLEL PROCESSING AND REDUNDANCY



MAJOR OBJECTIVES:

PROVIDE THE SYSTEM ARCHITECTURE TO ACHIEVE

- HIGH PERFORMANCE (.1 TO 10 GOPS)
- RELIABILITY FOR EXTENDED MISSIONS (1,000 - 10,000 HRS)
- AUTONOMY TO ADAPT TO CHANGING SITUATIONS AND MISSION MODES
- SEAMLESS HARDWARE AND SOFTWARE TRANSITIONS BETWEEN EPOCHS
- BUILT IN -
  - ON-LINE MODULE LEVEL VALIDATION
  - OFF-LINE COMPONENT LEVEL SELF TESTABILITY
- LOW POWER , WEIGHT, AND VOLUME
- RADIATION HARDNESS

KEY CONTACTS:

- H. BENZ (LaRC)
- J. DEYST (CSDL)
- T. DE YOUNG (DARPA)
- B. J. THOMAS (IBM)

MAJOR MILESTONES (1990-1995):

CONCEPT DEFINITION 1990

ARCHITECTURE DEFINITION 1990

LABORATORY PROTOTYPE 1991

BRASS BOARD PROTOTYPE 1993

FLIGHT SYSTEM PROTOTYPE 1995

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
FLIGHT ELEMENTS
ADVANCED AVIONICS ARCHITECTURE

NOVEMBER 1989

TECHNOLOGY ISSUES:

INTERCONNECTION TOPOLOGY

THROUGHPUT OVERHEADS
- PARALLEL COMPUTATION
- INFORMATION TRANSFER
- FAULT TOLERANCE

SOFTWARE
- OPERATING SYSTEM
- REDUNDANCY MANAGEMENT

QUANTIFIABLE PERFORMANCE AND RELIABILITY

VALIDATION METHODOLOGY

LOW POWER/SMALL FEATURE SIZE/RADIATION HARDNESS

CANDIDATE PROGRAMS:

LUNAR/MARS INITIATIVE

NASP

FUTURE AUTONOMOUS SPACECRAFT

MAJOR ACCOMPLISHMENTS:

RECOGNITION OF THE NEED FOR SUCH SYSTEMS.

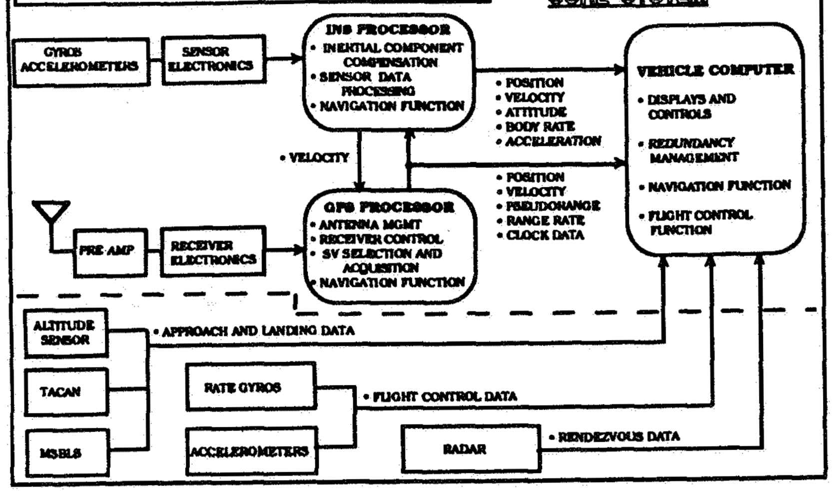
SIGNIFICANT MILESTONES:

91	92	93	94	R & D BASE
93	94	95	96	ADV. DEVEL.
95	96	97	98	FLIGHT SYSTEM

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
FLIGHT ELEMENTS
INTEGRATED GPS/GN&C

NOVEMBER 1989

INTEGRATED GPS/GN&C CONCEPT



MAJOR OBJECTIVES

- REDUCE MAINTENANCE COSTS
  - REDUCED LRU COUNT
  - HIGHER MTBF
- REDUCE WEIGHT, POWER, AND VOLUME
- AVOID OBSOLESCENCE OF DELETED SYSTEMS
- REDUCE VEHICLE LAUNCH AND TURNAROUND TIME
  - TESTING - CALIBRATION - ALIGNMENT
- DEVELOP COMMON MODULAR SYSTEMS FOR MULTIPLE NASA APPLICATIONS
- PROVIDE AUTONOMOUS NAVIGATION CAPABILITY
  - ASCENT - ORBIT - REENTRY
- PROVIDE AUTOLAND CAPABILITY
- REDUCE GROUND SUPPORT
- PROVIDE ATTITUDE DETERMINATION CAPABILITY
  - ELIMINATE SENSORS THAT PROVIDE ATTITUDE UPDATE

KEY CONTACTS

PARTICIPANTS

TOM BARRY - NASA/JSC
JIM BLUCKER - NASA/JSC
MANNY FERNANDEZ - LITTON
HENDRIK GELDERLOOS - HONEYWELL
IRVING HIRSCH - BOEING AEROSPACE
PENNY SAUNDERS - NASA/JSC
AL ZEITLIN - ROCKWELL/STSD

SUPPLIERS

- AUTONETICS
- COLLINS
- HAMILTON STANDARD
- HONEYWELL
- LITTON
- MOTOROLA
- NORTHROP
- RAYTHEON
- SMITH INDUSTRIES
- TEXAS INSTRUMENTS

USERS

- BOEING (ALS; E-6; AOA; AIWS)
- MDAC (SPACE STATION)
- ROCKWELL (NSTS; NASP; GUNSHIP)
- NASA (NSTS; SPACE STATION; OMV; SHUTTLE C; EDO)
- ARMED SERVICES (VARIOUS AIRCRAFT APPLICATIONS)
- JOINT PROGRAM OFFICE (NASP)
- FAA
- DARPA (GPS GUIDANCE PACKAGE)

FACILITIES

- NASA JSC GPS LABORATORY
- AF GEOPHYSICS LABORATORY
- JET PROPOLUSION LABORATORY
- GPS JPO GPS STANDARD AND PRECISE POSITIONING SERVICE
- NASA AMES MOBILE DIFFERENTIAL GPS GROUND FACILITY
- OTHER GOVERNMENT AND CONTRACTOR FACILITIES

MAJOR MILESTONES

- STANDARD RLG INS AND GPS INTEGRATED SYSTEMS DELIVERED TO NAVY AND AIR FORCE
- INTEGRATED GPS/INS SYSTEMS DELIVERED FOR AF RC-135 AIRCRAFT
- INTEGRATED GPS/INS SYSTEM FOR REMOTELY PILOTED VEHICLE SUCCESSFULLY TESTED
- INS WITH EMBEDDED GPS RECEIVER IN PRODUCTION FOR CIVIL AVIATION (FOREIGN)
- HELICOPTER AND AIRCRAFT LANDING TESTS USING DIFFERENTIAL GPS SYSTEMS CONDUCTED BY NASA-AMES
- HIGH PRECISION ORBIT NAVIGATION FILTER (KALMAN) DEVELOPED BY NASA-JSC
- RELATIVE NAVIGATION CAPABILITY FOR RENDEZVOUS OPERATIONS INVOLVING TWO VEHICLES WITH GPS RECEIVERS EVALUATED BY NASA-JSC

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OF POOR QUALITY

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
FLIGHT ELEMENTS
INTEGRATED GPS/GN&C

NOVEMBER 1989

TECHNOLOGY/APPLICATION ISSUES

- ACQUISITION OF TARGET VEHICLE DATA FOR AUTONOMOUS NAVIGATION DURING RENDEZVOUS, PROXIMITY, AND DOCKING OPERATIONS
  - COOPERATIVE TARGET
  - 'ANCHOR' SATELLITE
- VEHICLE ATTITUDE DETERMINATION USING GPS
  - ANTENNA SEPARATION LIMITED BY VEHICLE DIMENSIONS
- TRACKING SATELLITE VEHICLE SIGNAL THROUGH PLASMA
- MEETING AUTOLAND PERFORMANCE REQUIREMENTS
  - ACCURACY OF ALTITUDE DATA
- GPS UTILIZATION ABOVE 11,000 NM (e.g.; LUNAR MISSION RETURN)
  - REDUCED SATELLITE VEHICLE VISIBILITY

CANDIDATE PROGRAMS

- ASSURED SHUTTLE AVAILABILITY (ASA)
- SHUTTLE C
- EXTENDED DURATION ORBITER (EDO)
- ASSURED CREW RETURN VEHICLE (ACRV)
- SPACE STATION
- ORBITAL MANEUVERING VEHICLE
- ADVANCED LAUNCH STAGE
- ADVANCED UPPER STAGES
- NATIONAL AERO SPACE PLANE (NASP)
- LUNAR AND MARS MISSIONS RETURN

MAJOR ACCOMPLISHMENTS

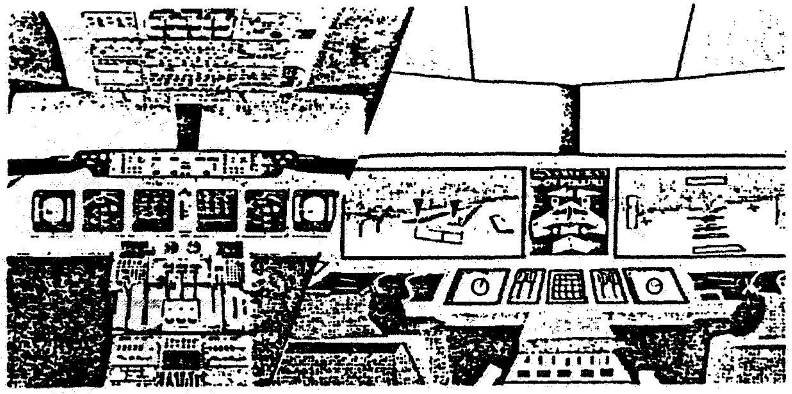
- F-15 FLIGHT TESTS DEMONSTRATE INERTIAL NAVIGATION ASSEMBLY CAPABILITY TO PROVIDE NAVIGATION AND FLIGHT CONTROL DATA - 1988
- INTEGRATED INS WITH EMBEDDED GPS FLOWN IN BOEING 767
  - FLIGHT TESTS PROGRAM - 1988
- FAA CERTIFICATION OF INS WITH EMBEDDED GPS - LATE 1990
- NATIONAL AERO SPACE PLANE SUBSYSTEM CONSORTIUM INVESTIGATING ANTENNA DESIGNS, ADVANCED ELECTRONICS, PLASMA TRANSMIT/RECEIVE LIMITATIONS
- SHUTTLE INTEGRATED GPS/GN&C CONCEPT AND FEASIBILITY STUDY
  - STUDY COMPLETE - 1990
  - FLIGHT DEMONSTRATION - 1993
- PRELIMINARY DESIGN STUDY OF INTEGRATED GPS & INS (MSFC)
  - INTEGRATED AND SEPARATE INS/GPS
  - MODULARIZED CONFIGURATION
- LABORATORY SIMULATIONS AND EVALUATIONS
  - ON-ORBIT OPERATIONS
  - AUTONOMOUS NAVIGATION
  - AUTOLAND

SIGNIFICANT MILESTONES

- IMPLEMENT STANDARD, MODULAR GPS RECEIVER
  - COST EFFECTIVE
  - SUPPORTS MULTIPLE PROGRAMS
  - CONFIGURABLE TO SPECIFIC APPLICATION.
  - INCLUDE TESTABILITY AS DESIGN REQUIREMENT
- CONDUCT TRADE STUDY OF TECHNIQUES TO ACCOMPLISH AUTOLAND, INCLUDING A FLIGHT DEMONSTRATION
- CONDUCT TRADE STUDY OF TECHNIQUES TO PERFORM AUTONOMOUS NAVIGATION, BY MISSION PHASE, FOR VARIOUS TRANSPORTATION PROGRAMS
  - ASCENT - ORBIT - REENTRY
- CONDUCT TRADE STUDY OF TECHNIQUES FOR GPS DETERMINATION OF VEHICLE ATTITUDE, INCLUDING A FLIGHT DEMONSTRATION

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
FLIGHT ELEMENTS
ADVANCED DISPLAYS AND CONTROLS

ADVANCED DISPLAYS & CONTROLS CONCEPTS:



MD11 COCKPIT ADVANCED COCKPIT TECHNOLOGY CONCEPT

MAJOR OBJECTIVES:

- LOWER COST, IMPROVED MAINTAINABILITY/RELIABILITY
- FOR SHUTTLE IN PARTICULAR, ELIMINATE PARTS/SKILLS OBSOLESCENCE
- REDUCED WEIGHT, VOLUME, AND POWER CONSUMPTION
- INHERENT GROWTH CAPABILITY FOR NEW FUNCTIONS OR ADVANCING TECHNOLOGY (I.E., PAYLOAD USER I/F)
- IMPROVEMENT IN PILOT'S SITUATIONAL AWARENESS
- REDUCTION IN PILOT'S/OPERATOR'S WORKLOAD
- IMPROVED FLIGHT SAFETY AND OPERATING EFFICIENCY
- COMMONALITY AND SOFTWARE RECONFIG. INTERFACE FOR FLEXIBILITY AND LOWER COST IN THE SUPPORT OF MULTIPLE PROGRAMS
- ELIMINATION OF PAPER/MANUAL CLUTTER THROUGH USE OF INTERACTIVE OPTICAL DISK TECHNOLOGY
- IMPROVED AUTONOMY THROUGH USE OF AI AND HUMAN-CENTERED AUTOMATION

KEY CONTACTS:

- DEAN KOCIAN/ WRIGHT R & D CENTER/ SUPERCOCKPIT PROGRAM
- DOC DOUGHERTY/ DARPA/ PILOT'S ASSOCIATE PROGRAM
- FRANK GOMER/ HONEYWELL/ PHEONIX RESEARCH CENTER
- GENE ADAM/ McDONNEL DOUGLAS/ "BIG PICTURE" DISPLAY PROGRAM
- ANDREW FARKAS/ JOHNSON SPACE CENTER/ EF2
- DR. McGREEVY/ AMES RESEARCH CENTER/ AEROSPACE HUMAN FACTORS DIV.
- BILL RUCKS/ ROCKWELL STSD
- TERRY EMERSON/ WRIGHT R & D CENTER/ COCKPIT INTEGRATION DIRECTORATE

FACILITIES:

- JSC/ EF2 D & C PORTION OF ADV. SYSTEMS DEVELOPMENT LAB
- JSC/ SHUTTLE ENGINEERING SIMULATOR
- LaRC/ ADV. CONCEPTS SIMULATOR & CREW STATION SYSTEMS RESEARCH LAB
- LaRC/ TRANSPORT SYSTEMS RESEARCH VEHICLE (AFT FLT. DECK W/COLOR DISPLAYS)
- ARC/ MAN VEHICLE SYSTEMS RESEARCH FACILITY & FLIGHT SIMULATION COMPLEX
- WRIGHT R & D CENTER/ SUPERCOCKPIT LAB & "MAGIC" COCKPIT FACILITY

MAJOR MILESTONES (1990 - 1995):

• SIGNIFICANT IMPROVEMENTS IN FLAT-PANEL TECHNOLOGIES	
— FULL-COLOR, SUNLIGHT-LEGIBLE LIQUID CRYSTAL DISPLAYS	FY 90-91
— FULL-COLOR PLASMA PANEL (15-IN. DIAG.), PHASE II SBIR	FY 91-92
• FLIGHT-WORTHY GRAPHICS GENERATORS CAPABLE OF REAL-WORLD 3-D PICTORIAL DISPLAYS	FY 91-92
• IMPROVEMENTS IN VOICE, TOUCH, AND HAND-CONTROLLER INPUT TECHNOLOGIES	FY 91-92
• FINALIZED SPACE STATION MULTI-PURPOSE APPLICATIONS CONSOLE DESIGN	FY 91-92
• RESULTS OF AIR FORCE SUPERCOCKPIT AND BIG PICTURE PROGRAMS	FY 92-93
• RESULTS OF DARPA PILOT'S ASSOCIATE AND HDTV STUDIES	FY 93-94
• RESULTS OF NASA AIRCRAFT SAFETY/AUTOMATION PROGRAM	FY 93-94
• ORBITER GLASS COCKPIT DISPLAY UPGRADE	FY 93-95

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SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
FLIGHT ELEMENTS
ADVANCED DISPLAYS AND CONTROLS

TECHNOLOGY ISSUES:

- ORBITER DOWN-TIME FOR HARDWARE INSTALLATION
- MATURITY OF FLAT-PANEL DISPLAY TECHNOLOGY
- DANGER OF MAKING CREW BORED/MACHINE MINDERS
- ADVANCED DISPLAY SYMBOLOGY/PICTORIAL FORMATS
- MATURITY AND UTILIZATION OF AI TECHNOLOGY
- GROWTH AND FLEXIBILITY
- INTERACTIVE DISPLAY/CONTROL NEEDS MORE RESEARCH
- IMPACT OF ELECTRONIC DISPLAYS & CONTROLS (ALL-GLASS COCKPIT) ON CREW TRAINING

CANDIDATE PROGRAMS:

- SPACE SHUTTLE (ASSURED SHUTTLE AVAILABILITY)
- SPACE STATION MPAC
- NATIONAL AERO-SPACE PLANE
- COMBINED AFT MANIPULATOR WORKSTATION (ORBITER)
- AVIATION SAFETY/AUTOMATION
- ADVANCED COCKPIT/FLIGHT MANAGEMENT TECHNOLOGY (PROPOSED FY 92 NEW INITIATIVE IN AERO)

MAJOR ACCOMPLISHMENTS:

- EMERGENCE OF SEVERAL GLASS COCKPITS IN MILITARY AND COMMERCIAL AIRCRAFT (747-400, GULFSTREAM G IV, MD11, F-15E, AND BEECH STARSHIP)
- EMERGENCE OF COLOR ACTIVE-MATRIX LCD TECHNOLOGY
- EMERGENCE OF HIGH-DEFINITION TV (HDTV) TECHNOLOGY
- EMERGENCE OF REAL-TIME GRAPHICS DISPLAY TECHNOLOGY
- EMERGENCE CONTINUOUS-SPEACH, SPEAKER-INDEPENDENT VOICE RECOGNITION TECHNOLOGY

SIGNIFICANT MILESTONES:

• SPACE STATION PERMANENT MANNED CAPABILITY, MPAC	1995-96
• CREW EMERGENCY RETURN VEHICLE	1997
• MANNED LUNAR MISSION	2001
• MANNED MARS MISSION	2016
• ORBITER BLOCK II COCKPIT	- - - -

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM

FLIGHT ELEMENTS

ADVANCED COMMUNICATIONS AND TELEMETRY

NOVEMBER 1989

ADVANCED TECHNOLOGY :

1. GALLIUM ARSENIDE VHSIC
2. FIBER OPTICS
3. ADVANCED ANTENNA DESIGN
4. FREE SPACE OPTICAL COMMUNICATION
5. ADVANCED SIGNAL PROCESSING
6. ADVANCED MODEM / CODEC DEVELOPMENT

MAJOR OBJECTIVES:

. UTILIZE NEW SPECTRUM
. MAXIMIZE DATA RATE THROUGH AVAILABLE SPECTRUM
. PROVIDE FLEXIBLE WIDEBAND DATA DISTRIBUTION NETWORKS (DDNs)
. VERY LOW POWER CONSUMPTION
. DENSE PACKAGING
. RFI/EMI IMMUNITY
. GRACEFUL DEGRADATION
. MULTIBEAM ANTENNAS

KEY CONTACTS:

JSC/ K. LAND
LeRC/ R. LEONARD, J. HARROLD
GSFC/ M. FITZMAURICE, D. DALTON
NMSU/ F. CARDEN, S. HORAN

KEY FACILITIES:

JSC- C&T ENGIINEERING LAB.
LeRC: MMW TEST FACILITY; DSP LAB.
GSFC: LASER COM. LAB.
NMSU- CENTER FOR SPACE TELEM. & TELECOM. SYSTEMS

MAJOR MILESTONES:

DARPA MIMIC PHASE I (MAY'89), PHASE II (1991-94)

EVOLUTION OF STANDARDS
- FDDI STANDARD

ACTS COM SYSTEM
32 GHz TWTA 7W 1992, 50W 1995

"COMMON" SIGNAL PROCESSOR (CSP, GSP, EMSP, GASP)

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
FLIGHT ELEMENTS
ADVANCED COMMUNICATIONS AND TELEMETRY

NOVEMBER 1989

TECHNOLOGY ISSUES:

1. PRODUCIBILITY OF GaAS
2. POWER LIMITS ON DISTRIBUTION
3. PACKAGING @ HIGH (> 20 GHz)
4. POINTING ACCURACY/ STABILITY
5. SOFTWARE DEVELOPMENT
6. SOFTWARE DEVELOPMENT

CANDIDATE PROGRAMS:

- SPACE STATION
- STS UPGRADES
- LUNAR MARS EXPLORATIONS
- ATDRSS

MAJOR ACCOMPLISHMENTS:

- 32GHz PHASED ARRAY UNDER DEVELOPMENT
- Gbps FIBER OPTICS LINKS IN LABORATORY TEST
- VHSIC PHASE I CHIPS AVAILABLE

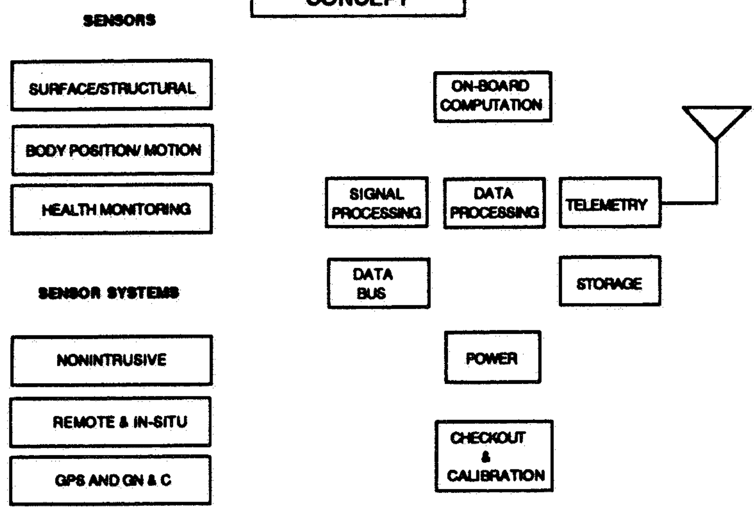
SIGNIFICANT MILESTONES:

- SMALLER, LIGHTER, LOWER POWER PACKAGING
- IMPROVED RELIABILITY
- STANDARDIZATION OF INTERFACES

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
FLIGHT ELEMENTS

ADVANCE SENSORS & INSTRUMENTATION

CONCEPT



MAJOR OBJECTIVES

LOW, WEIGHT, VOLUME, POWER & COST

	CURRENT CAPABILITY	NEW REQUIREMENTS
SENSORS - AIR DATA - TRANSITION - PRESSURE/TEMPERATURE INSTRUMENTATION		HIGH ACCURACY HIGH SPATIAL DENSITY HIGH FREQUENCY HIGH RELIABILITY
NONINTRUSIVE AIR DATA		
SMART DATA SYSTEMS		300Mb/sec
ON-BOARD PROCESSING		DATA COMPRESSION
ON-BOARD COMPUTATION		DATA PRODUCTS
ON-BOARD STORAGE		> TERABIT
DATA BUS		
CHECKOUT/CALS/AUTO RANGE		
POWER		
SOLID STATE LASERS		2 JOULE SOLID STATE
LIGHT WEIGHT OPTICS		
LG REFLECTORS/ANTENNAS		
SMART STRUCTURES/SERVOS		NDE
DETECTORS		
CRYOGENICS		20K COOLERS

KEY CONTACTS

LaRC	
GLEN TAYLOR	88-928-1733
BRUCE CONWAY	88-928-4755
DON LAWRENCE	88-928-5380
MSFC	
JOE ZIMMERMAN	88-824-3458
JSC	
PAUL SOLLOCK	88-525-8225
MIKE GAUDIANO (EH6)	88-525-8318
G.HARMON (EH6)	
K. DOUGLAS (LOCKHEED)	
K.PETERSON (NOVA SENSORS)	

FACILITIES

- CLEAN ROOMS
- ENVIRONMENTAL CHAMBERS
- THERMO VAC CHAMBERS
- CALIBRATION
- NDE LABS
- SENSOR LABS
- ENVIRONMENTAL
- R & QA
- MICROELECTRONIC/MATERIALS

- EMI/EMC
- CAD/CAE & ASIC
- LASER LAB
- DETECTOR LAB
- COMPUTATIONAL SUPPORT

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
FLIGHT ELEMENTS

ADVANCE SENSORS & INSTRUMENTATION

TECHNOLOGY ISSUES:

- O SMART SKINS - FIBEROPTIC TRANSDUCERS & TRANSMISSION LINES EMBEDDED IN ADVANCED COMPOSITES
- O MICRO-MACHINED TRANSDUCERS - EMPLOYING CLASSICAL SEMICONDUCTOR PROCESSING TECHNIQUES TO BUILD MECHANICAL STRUCTURES & TRANSDUCERS
- O SMART TRANSDUCERS - INTEGRATION OF A TRANSDUCER, SIGNAL CONDITIONERS, PROGRAMMABLE EMBEDDED MICROCONTROLLERS
- O ADVANCED INSTRUMENTATION - INTEGRATION OF SMART TRANSDUCERS INTO A DISTRIBUTED BUS OR FAULT TOLERANT LOCAL AREA NETWORK (LAN)
- O HYBRID ELECTRONICS & SURFACE MOUNT TECHNOLOGY
- O INTEGRATION OF DIVERSE TRANSDUCERS & SIGNAL TYPES INTO SMART TRANSDUCER MODULE
- O APPLICATION SPECIFIC INTEGRATED CIRCUIT (ASIC) DESIGN CAPABILITY TO MINIMIZE WEIGHT, POWER, & VOLUME PARAMETERS
- O SMART, MINIATURE & RELIABLE DATA ACQUISITION SYSTEMS (DAS)
- O ON BOARD DATA PROCESSING
- O ON BOARD COMPUTATION
- O ON BOARD STORAGE
- O ADVANCED DATA TRANSMISSION
- O LASER - BASED RENDEZVOUS SYSTEMS
- O 2 MICRON LASERS FOR EYE-SAFE AND WINDS
- O LIGHT WEIGHT OPTICS FOR WIND SHEAR LIDAR
- O CRYOGENICS : DEVELOP 20K COOLERS FOR SOLVING MOST DETECTOR PROBLEMS
- O LARGE REFLECTORS/ANTENNAS
- O INVESTIGATE & DEVELOP SENSORS FOR SMART STRUCTURES
- O DEVELOP MORE EFFECTIVE ELECTROMAGNETIC MEASUREMENT, MODELING, INJECTION & DETECTION SENSORS

CANDIDATE PROGRAMS:

UPGRADE OF ORBITER MODULAR AUXILIARY DATA SYSTEM (MADS)

UARS

EOS

SHUTTLE C

SPACE STATION FREEDOM

ELV

MISSION TO PLANET EARTH

MANNED MISSION TO MARS

LUNAR BASE

MAJOR ACCOMPLISHMENTS

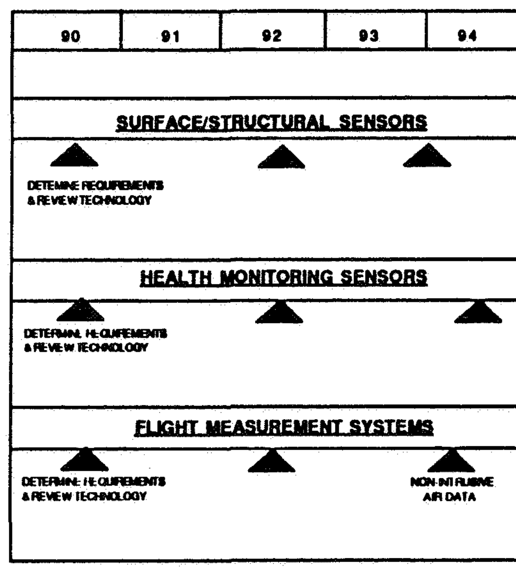
LIDAR

OPTICAL DISK

HIGH PRESSURE STAND ALONE PRESSURE MEASUREMENT DEVICE

ON-BOARD COMPUTING

SIGNIFICANT MILESTONES



GOALS

- O SMART SENSORS
- O SMART SKINS
- O SMART, SMALL & RELIABLE DAS
- O ON BOARD DATA PROCESSING
- O ON BOARD COMPUTATION
- O ON BOARD STORAGE
- O ADVANCED DATA TRANSMISSION
- O SMART STRUCTURES
- O LASER APPLICATIONS
- O DETECTORS
- O NDE

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
FLIGHT ELEMENTS
FAULT DETECTION AND FAULT MANAGEMENT

TECHNOLOGY CONCEPT:

Sensors
Reconfiguration
Design Knowledge Capture
Operations
Software
FAULT MANAGEMENT: AN INTEGRATED APPROACH
FDIR
Diagnosis
Detection/Isolation
Hardware
Testability
Digraph Matrix Analysis
Performance

MAJOR OBJECTIVES:

- Monitoring, diagnosis, and reconfiguration at all system levels
- Unambiguous isolation of failures
- Integration with maintenance support and operations
- Optimize system operations to manage degraded system performance
- Lower development/operations costs
- Develop fault tolerant/FDIR requirements and specifications

KEY CONTACTS:

ARC - A. Patterson-Hine
JSC - J.T. Edge
LaRC - C. Meissner
MSFC - D. Weeks
KSC - T. Davis
JPL - D. Miller
HQ - G. Swietek (OSS), J. Di Battista (OAST)

Industry contacts: TBD

KEY FACILITIES:

JSC Testbeds
MSFC SSM/PMAD & ECLSS Testbeds
ARC Advanced Architectures Testbed

MAJOR MILESTONES:

- Review technology, investigate leveraging opportunities (1990)
- Define concept and develop integrated program technology development and integration plan(1990)
- Develop integrated testbed(s) (1992)
- Proof of concept demo (1993)

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
FLIGHT ELEMENTS
FAULT DETECTION AND FAULT MANAGEMENT

TECHNOLOGY ISSUES:

- Design accomodation of fault detection and fault management (FD/FM)
- Integrated program database support of FD/FM
- Design knowledge capture to support FD/FM
- Evolutionary, automated modeling techniques
- Scalability of current technologies
- Scope of human interface/interaction
- Software FD/FM
- Development of smart sensors and specialized processing functions with high reliability and lower power consumption
- Autonomous detection and recovery from faults

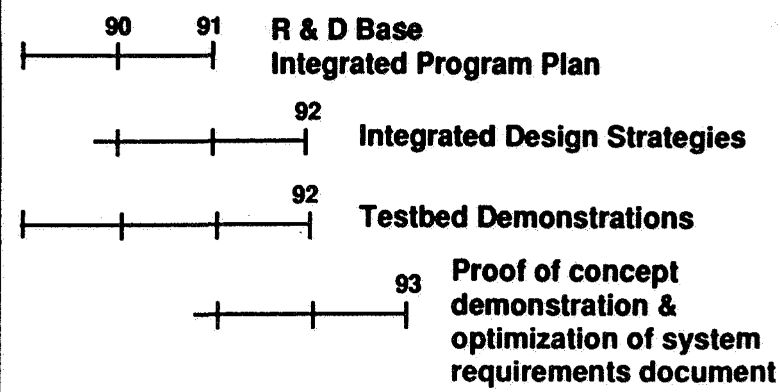
CANDIDATE PROGRAMS:

- SSFP
- ALS
- Shuttle C
- Lunar/Mars missions

MAJOR ACCOMPLISHMENTS:

- Space Station Advanced Development Program already addressing some of the technology issues
- DARPA and ONR activities leveraged to some of the technology issues
- Basic testbeds already in place
- Core Technology Team available

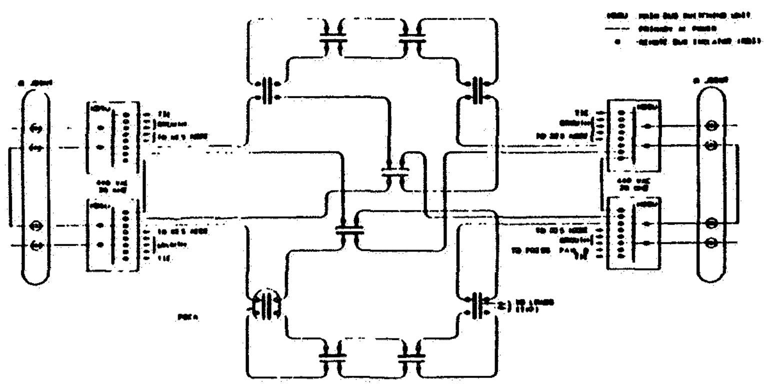
SIGNIFICANT MILESTONES:



SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
FLIGHT ELEMENTS
ADVANCED ELECTRICAL POWER, DISTRIBUTION AND CONTROL

NOVEMBER 1989

ADVANCED ELECTRICAL POWER, DISTRIBUTION AND CONTROL



SPACE STATION RING DISTRIBUTION SYSTEM (EXTERNAL LOAD AREAS ONLY).

MAJOR OBJECTIVES:

- REDUCE COSTS TO LEO, LUNAR/MARS SURFACE
- REDUCE WEIGHT
- INCREASE AVAILABLE POWER/ENERGY
- IMPROVED REDUNDANCY MANAGEMENT
- IMPROVED POWER QUALITY, USER AVAILABILITY
- FAULT TOLERANT, INTEGRATED BITE

KEY CONTACTS:

H. BRANDHORST/LeRC
I. HANSEN/LeRC
J. MILDICE/GDSS
J. BIESS/TRW
R. BECHTEL/MSFC

FACILITIES:

LeRC POWER TECHNOLOGY TESTBED

MAJOR MILESTONES (1990-1995):

SPACE STATION FREEDOM

1990 ADV. DEV. TEST BED DEMOS

ADVANCED LAUNCH SYSTEM

1990 —— 1992 ADV. DEV. DEMO OF IEPS

CIVIL AERO-FBL/PBW

TECH. VALID. ▽ DDT&E ▽ FLIGHT DEMO. ▽

1991 —— 1993 | 1995 | 1996

LUNAR/MARS INITIATIVE

1992 —— 1995

STUDIES ---------- ADV. DEV. PROG.

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
FLIGHT ELEMENTS
ADVANCED ELECTRICAL POWER, DISTRIBUTION AND CONTROL

NOVEMBER 1989

TECHNOLOGY ISSUES:

END-TO-END EPS MANAGEMENT WITH FAULT LIMITING, RECOVERY AND FAIL SAFE/FAIL OPERATIONAL RECONFIGURATION

DISTRIBUTED vs. DEDICATED PMAD FOR REDUNDANCY, RELIABILITY, OPERABILITY

BITE INTEGRATED INTO DESIGN AT MANUFACTURE

ASA: DDT&E FOR ELECTRICAL ACTUATORS RETROFIT BY INSPECTION DATE

CANDIDATE PROGRAMS:

ADVANCED LAUNCH SYSTEM

ASSURED SHUTTLE AVAILABILITY

CIVIL AERO - POWER-BY-WIRE/FLY-BY-LIGHT

LUNAR/MARS INITIATIVE

AF/WRDC - MORE ELECTRIC AIRPLANE - RETROFIT F-16

DAVID TAYLOR SHIP R&DC - ELECTRONIC NAVY

MAJOR ACCOMPLISHMENTS:

- DEMONSTRATED MULTI-REDUNDANT, FAULT TOLERANT, MICROPROCESSOR CONTROLLED SSF 20 kHz ELECTRICAL POWER DISTRIBUTION SYSTEM
- DEMONSTRATED VARIABLE SPEED DRIVES TO 200 HP, ELECTRICAL ACTUATORS TO 25 HP/DESIGNS TO 75 HP

SIGNIFICANT MILESTONES:

1990 R&T BASE - COMPS, POWER SEMI'S

1991 1992 ADV. DEV. - SSF, ALS

1995 DDT&E

▽ LEV. 5 MATURITY

△ NSTS NEED DATE

△ LUNAR/MARS NEED DATE

VALIDATION NEAR COMPLETE:

- ADVANCED HIGH POWER PMAD CONCEPTS APPLICABLE TO CANDIDATE PROGRAMS
- ADVANCED MOTOR CONTROL ENABLING INDUCTION MOTOR EXPLOITATION FOR LUNAR/MARS VEHICLES

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
FLIGHT ELEMENTS
EMA/POWER SYSTEMS

NOVEMBER 1989

TECHNOLOGY ISSUES:

ASA: DDT&E FOR EMA RETROFIT BY INSPECT. DATE

END-TO-END EPS MANAGEMENT WITH FAULT LIMITING, RECOVERY AND FAIL SAFE/FAIL OPERATIONAL RECONFIGURATION

DISTRIBUTED vs. DEDICATED PMAD FOR REDUNDANCY, RELIABILITY, OPERABILITY

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CANDIDATE PROGRAMS:

ADVANCED LAUNCH SYSTEM

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CIVIL AERO - POWER-BY-WIRE/FLY-BY-LIGHT

LUNAR/MARS INITIATIVE

AF/WRDC - MORE ELECTRIC AIRPLANE - RETROFIT F-16

DAVID TAYLOR SHIP R&DC - ELECTRONIC NAVY

MAJOR ACCOMPLISHMENTS:

- PRELIMINARY ASA STUDIES COMPLETED
- KSC TURNAROUND FLOW ANALYSIS INITIATED
- TECHNOLOGY DEMOS/ASSESSMENT INITIATED
- DEMONSTRATED ELECTRIC ACTUATORS/ DRIVES TO 25 HP/DESIGNS TO 75 HP
- DEMONSTRATED MULTI-REDUNDANT, FAULT TOLERANT, MICROPROCESSOR CONTROLLED SSF 20 kHz ELECTRICAL POWER DISTRIBUTION SYSTEM

SIGNIFICANT MILESTONES:

1990 R&T BASE - COMPS, POWER SEMI'S

1991 1992 ADV. DEV. - SSF, ALS

1995 DDT&E

▽ LEV. 5 MATURITY

△ NSTS NEED DATE

△ LUNAR/MARS NEED DATE

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- ADVANCED MOTOR CONTROL ENABLING INDUCTION MOTOR EXPLOITATION

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
FLIGHT ELEMENTS
EMA/POWER SYSTEMS

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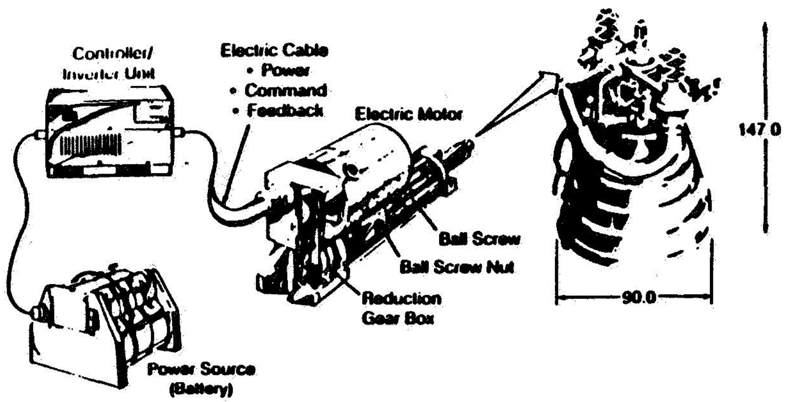
EMA/POWER SYSTEMS



MAJOR OBJECTIVES:

REDUCE KSC TURN AROUND COSTS ; INCREASE LAUNCH RATE
- ELIMINATE EXCESSIVE MAN TESTS AND VERIFICATIONS
- ADD SELF CHECKOUT THROUGH BUILT-IN-TEST (BITE)
- ELIMINATE GROUND SUPPORT CARTS AND EQUIPMENT

IMPROVE REDUNDANCY, RELIABILITY AND DECREASE WEIGHT
- MATCH FLIGHT CONTROLS, POWER SOURCE, ACTUATORS
- USE DEMAND DRIVEN SYSTEM - SIMPLE IMPLEMENTATION

IMPROVE DISPATCH RELIABILITY
- AUTOMATED VEHICLE CHECKOUT
- LOW STANDBY POWER/ENERGY
- ELIMINATE HYDRAULIC SILTING

REDUCE STANDDOWN TIME

TECHNOLOGY TRANSFER TO CIVIL SECTOR

KEY CONTACTS:

G. SUNDBERG/LeRC
J. T. EDGE/JSC
C. CORNELIUS/MSFC
C. McCLESKEY/KSC
B. LUM/RI-DOWNEY
S. TAQUI/GDSS
J. ANDERSON/BAC

FACILITIES:

MSFC ACTUATOR TEST FACILITY
ROCKWELL-DOWNEY
AIRFORCE WRDC-FLIGHT DYNAMICS

MAJOR MILESTONES (1990-1995):

ASSURED SHUTTLE AVAILABILITY (ASA)

1990 TECHNOLOGY, RISK, COST ASSESSMENT

ADVANCED LAUNCH SYSTEM

EMA DESIGNS ▽ COMPLETE DEMOS/ COST/OPERABILITY ▽ IOC ▽

1990	1991	1992		2000

CIVIL AERO-FBL/PBW

▽ VALID. STUDIES REVIEW TECH. DDT&E ▽ FLIGHT DEMO. ▽

1991	1992	1993	1994	1995	1996

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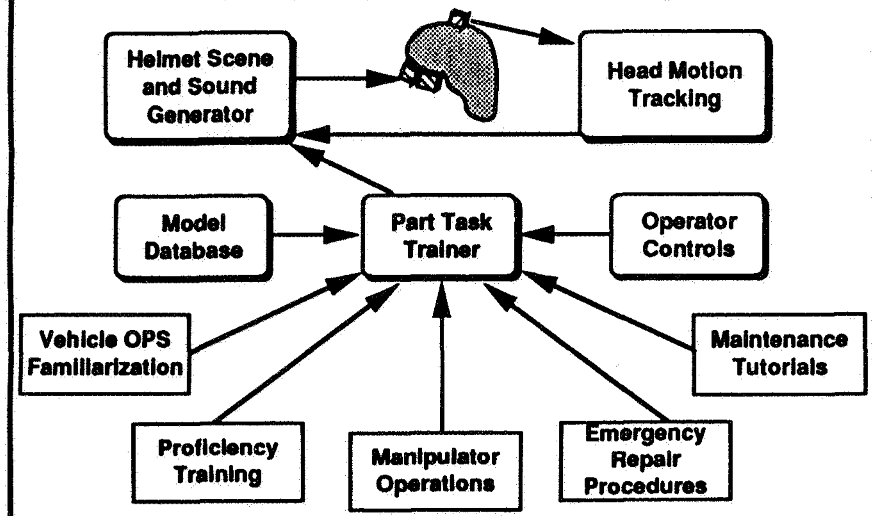
SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
FLIGHT ELEMENTS
IN - FLIGHT CREW TRAINING

IN - FLIGHT CREW TRAINING



MAJOR OBJECTIVES:

- Provide more effective training environments
  - Video or animated task descriptions
  - Interactive training environments
    - •• Computer generated, synthetic 3-D training scenarios
    - •• Active computer control of hand input devices during scene playback for tactile training
- Provide accelerated in-flight training capability
  - Refresh crew skills
  - Practice unplanned contingency operations in a realistic environment
- Enhance crew preparedness
- Enhance crew safety

KEY CONTACTS:

C. Gott / JSC / FM8

P. Galicki / JSC / FM8

S. Murray / JSC / VG3

FACILITIES:

- Integrated Graphics Operations Analysis Laboratory (IGOAL)
  - RMS MIL Simulators: Shuttle, SSF
  - Proximity Operations Simulators: Shuttle, Shuttle-C, OMV, MMU
- JSC Systems Engineering Simulator

MAJOR MILESTONES (1990 - 1995)

- Test and evaluate faster machines with graphics capability
- Test simulation interaction with current hardware
- Develop non-realtime system with dynamics and collision detection on current hardware
- Test and evaluate stereo graphics hardware
- Investigate malfunction training concepts to establish viability

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
FLIGHT ELEMENTS
IN - FLIGHT CREW TRAINING

TECHNOLOGY ISSUES:

- Integration with existing flight systems
- Display and processor capabilities
  - Low weight, volume and power requirements
  - Provide for multiple trainees interacting within a realistic synthetic 3-D training scenario
  - Allow local storage of "digital" tapes of training scenarios
  - Facilities to upload from remote training library

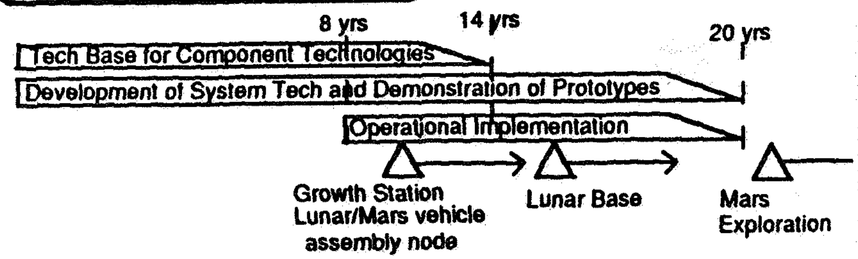
CANDIDATE PROGRAMS:

- Space Station Freedom (SSF)
  - Remote Manipulator Systems (SRMS, SSRMS)
  - Flight Telerobotic Servicer (FTS)
  - Orbital Maneuvering Vehicle (OMV) Piloting
  - Shuttle Piloting and Landing
- Space Shuttle
  - Remote Manipulator System
  - Proximity Operations
  - Approach and Landing

MAJOR ACCOMPLISHMENTS:

- Development of kinematic and dynamic simulators for generic remote manipulator systems
- Teleoperated systems technology investigations
  - Helmet mounted display
  - Stereoscopic vision systems
- Man-in-the-loop simulator development
  - Manipulator Simulations: SRMS, SSRMS, FTS
  - Spacecraft Simulators: Shuttle, OMV
- RMS Partial Task Trainer hosted on Silicon Graphics IRIS 4D/70GT
  - Kinematic simulation with near real-time performance using low fidelity models
  - RMS control panel and hand controllers

SIGNIFICANT MILESTONES:



- Identify appropriate training tasks
- Determine system requirements
- Define system architecture
- Develop and integrate system hardware
- Develop training software for prototype system
- Flight demonstration of training capabilities
- Operational trainer development
- Training plan implementation

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SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM

FLIGHT ELEMENTS

ADVANCED AVIONICS SYSTEMS ARCHITECTURES

NOVEMBER 1989

Technology Issues:

- Level of Fault Tolerance
- Cost vs. Reliability
- Utility of Building-Block Architectures
- Modeling/Test Mix for Validation
- Design for Launch-With-Failures
- EME-HARD Design and Assessment
- Software Development Environment
- ADA Software for High-Bandwidth Control

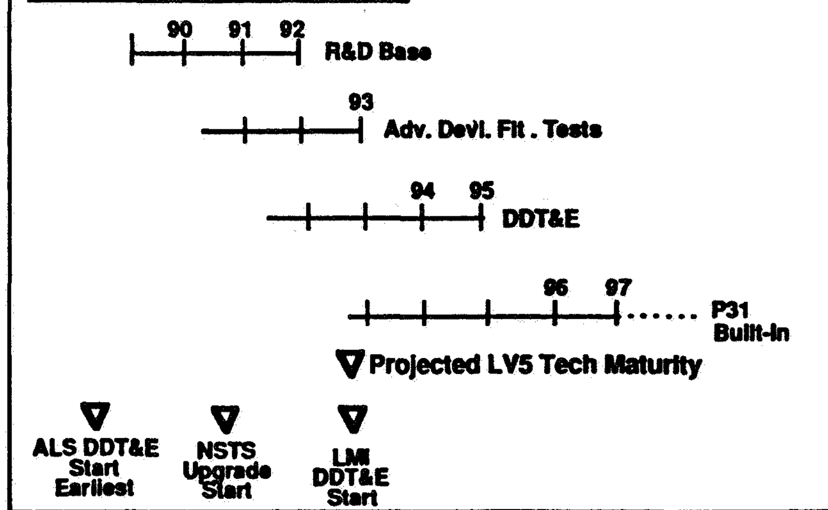
Candidate Programs:

- Assured Shuttle Availability, Unmanned Orbiter
- NASP, CERV
- Shuttle-C, ALS
- Existing Launch Vehicles
- SSP, Lunar Mars Initiative

Major Accomplishments:

- Space Station Avionics Design Captures Some Objectives
- ALS Requirements and Advanced Technology Development Meets/Exceeds Objectives
- Advanced Military Aircraft in DDT&E (A-12 and ATF) Captures Objectives and Developing Usable Hardware
- Commercial aircraft fault-tolerant / distributed systems

Significant Milestones:



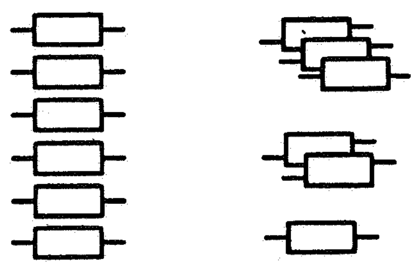
SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
FLIGHT ELEMENTS

NOVEMBER 1989

ADVANCED AVIONICS ARCHITECTURE

ADVANCED AVIONICS CONCEPTS

EXPLOIT THE POTENTIAL SYNERGISM BETWEEN PARALLEL PROCESSING AND REDUNDANCY



MAJOR OBJECTIVES:

PROVIDE THE SYSTEM ARCHITECTURE TO ACHIEVE

- HIGH PERFORMANCE (.1 TO 10 GOPS)
- RELIABILITY FOR EXTENDED MISSIONS (1,000 - 10,000 HRS)
- AUTONOMY TO ADAPT TO CHANGING SITUATIONS AND MISSION MODES
- SEAMLESS HARDWARE AND SOFTWARE TRANSITIONS BETWEEN EPOCHS
- BUILT IN -
  - ON-LINE MODULE LEVEL VALIDATION
  - OFF-LINE COMPONENT LEVEL SELF TESTABILITY
- LOW POWER , WEIGHT, AND VOLUME
- RADIATION HARDNESS

KEY CONTACTS:

- H. BENZ (LaRC)
- J. DEYST (CSDL)
- T. DE YOUNG (DARPA)
- B. J. THOMAS (IBM)

MAJOR MILESTONES (1990-1995):

CONCEPT DEFINITION 1990

ARCHITECTURE DEFINITION 1990

LABORATORY PROTOTYPE 1991

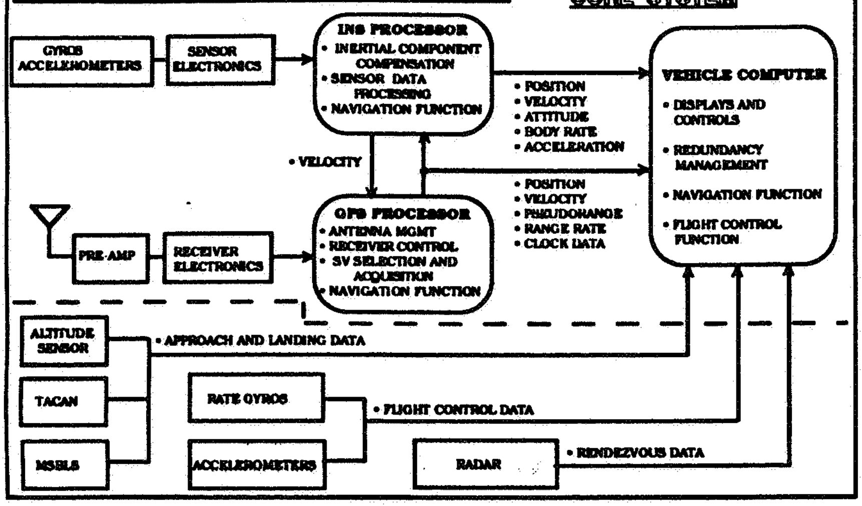
BRASS BOARD PROTOTYPE 1993

FLIGHT SYSTEM PROTOTYPE 1995

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
FLIGHT ELEMENTS
INTEGRATED GPS/GN&C

NOVEMBER 1989

INTEGRATED GPS/GN&C CONCEPT



MAJOR OBJECTIVES

- REDUCE MAINTENANCE COSTS
  REDUCED LRU COUNT
  HIGHER MTBF
- REDUCE WEIGHT, POWER, AND VOLUME
- AVOID OBSOLESCENCE OF DELETED SYSTEMS
- REDUCE VEHICLE LAUNCH AND TURNAROUND TIME
  TESTING - CALIBRATION - ALIGNMENT
- DEVELOP COMMON MODULAR SYSTEMS FOR MULTIPLE NASA APPLICATIONS
- PROVIDE AUTONOMOUS NAVIGATION CAPABILITY
  ASCENT - ORBIT - REENTRY
- PROVIDE AUTOLAND CAPABILITY
- REDUCE GROUND SUPPORT
- PROVIDE ATTITUDE DETERMINATION CAPABILITY
  ELIMINATE SENSORS THAT PROVIDE ATTITUDE UPDATE

KEY CONTACTS

PARTICIPANTS

TOM BARRY - NASA/JSC
JIM BLUCKER - NASA/JSC
MANNY FERNANDEZ - LITTON
HENDRIK GELDERLOOS - HONEYWELL
IRVING HIRSCH - BOEING AEROSPACE
PENNY SAUNDERS - NASA/JSC
AL ZEITLIN - ROCKWELL/STSD

SUPPLIERS

- AUTONETICS
- COLLINS
- HAMILTON STANDARD
- HONEYWELL
- LITTON
- MOTOROLA
- NORTHROP
- RAYTHEON
- SMITH INDUSTRIES
- TEXAS INSTRUMENTS

USERS

- BOEING (ALS; E-6; AOA; AIWS)
- MDAC (SPACE STATION)
- ROCKWELL (NSTS; NASP; GUNSHIP)
- NASA (NSTS; SPACE STATION; OMV; SHUTTLE C; EDO)
- ARMED SERVICES (VARIOUS AIRCRAFT APPLICATIONS)
- JOINT PROGRAM OFFICE (NASP)
- FAA
- DARPA (GPS GUIDANCE PACKAGE)

FACILITIES

- NASA JSC GPS LABORATORY
- AF GEOPHYSICS LABORATORY
- JET PROPOLUSION LABORATORY
- GPS JPO GPS STANDARD AND PRECISE POSITIONING SERVICE
- NASA AMES MOBILE DIFFERENTIAL GPS GROUND FACILITY
- OTHER GOVERNMENT AND CONTRACTOR FACILITIES

MAJOR MILESTONES

- STANDARD RLG INS AND GPS INTEGRATED SYSTEMS DELIVERED TO NAVY AND AIR FORCE
- INTEGRATED GPS/INS SYSTEMS DELIVERED FOR AF RC-135 AIRCRAFT
- INTEGRATED GPS/INS SYSTEM FOR REMOTELY PILOTED VEHICLE SUCCESSFULLY TESTED
- INS WITH EMBEDDED GPS RECEIVER IN PRODUCTION FOR CIVIL AVIATION (FOREIGN)
- HELICOPTER AND AIRCRAFT LANDING TESTS USING DIFFERENTIAL GPS SYSTEMS CONDUCTED BY NASA-AMES
- HIGH PRECISION ORBIT NAVIGATION FILTER (KALMAN) DEVELOPED BY NASA-JSC
- RELATIVE NAVIGATION CAPABILITY FOR RENDEZVOUS OPERATIONS INVOLVING TWO VEHICLES WITH GPS RECEIVERS EVALUATED BY NASA-JSC

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
FLIGHT ELEMENTS
INTEGRATED GPS/GN&C

NOVEMBER
1989

TECHNOLOGY/APPLICATION ISSUES

- ACQUISITION OF TARGET VEHICLE DATA FOR AUTONOMOUS NAVIGATION DURING RENDEZVOUS, PROXIMITY, AND DOCKING OPERATIONS
  - COOPERATIVE TARGET
  - 'ANCHOR' SATELLITE
- VEHICLE ATTITUDE DETERMINATION USING GPS
  - ANTENNA SEPARATION LIMITED BY VEHICLE DIMENSIONS
- TRACKING SATELLITE VEHICLE SIGNAL THROUGH PLASMA
- MEETING AUTOLAND PERFORMANCE REQUIREMENTS
  - ACCURACY OF ALTITUDE DATA
- GPS UTILIZATION ABOVE 11,000 NM (e.g.; LUNAR MISSION RETURN)
  - REDUCED SATELLITE VEHICLE VISIBILITY

CANDIDATE PROGRAMS

- ASSURED SHUTTLE AVAILABILITY (ASA)
- SHUTTLE C
- EXTENDED DURATION ORBITER (EDO)
- ASSURED CREW RETURN VEHICLE (ACRV)
- SPACE STATION
- ORBITAL MANEUVERING VEHICLE
- ADVANCED LAUNCH STAGE
- ADVANCED UPPER STAGES
- NATIONAL AERO SPACE PLANE (NASP)
- LUNAR AND MARS MISSIONS RETURN

MAJOR ACCOMPLISHMENTS

- F-15 FLIGHT TESTS DEMONSTRATE INERTIAL NAVIGATION ASSEMBLY CAPABILITY TO PROVIDE NAVIGATION AND FLIGHT CONTROL DATA - 1986
- INTEGRATED INS WITH EMBEDDED GPS FLOWN IN BOEING 767
  - FLIGHT TESTS PROGRAM - 1988
- FAA CERTIFICATION OF INS WITH EMBEDDED GPS - LATE 1990
- NATIONAL AERO SPACE PLANE SUBSYSTEM CONSORTIUM INVESTIGATING ANTENNA DESIGNS, ADVANCED ELECTRONICS, PLASMA TRANSMIT/RECEIVE LIMITATIONS
- SHUTTLE INTEGRATED GPS/GN&C CONCEPT AND FEASIBILITY STUDY
  - STUDY COMPLETE - 1990
  - FLIGHT DEMONSTRATION - 1993
- PRELIMINARY DESIGN STUDY OF INTEGRATED GPS & INS (MSFC)
  - INTEGRATED AND SEPARATE INS/GPS
  - MODULARIZED CONFIGURATION
- LABORATORY SIMULATIONS AND EVALUATIONS
  - ON-ORBIT OPERATIONS
  - AUTONOMOUS NAVIGATION
  - AUTOLAND

SIGNIFICANT MILESTONES

- IMPLEMENT STANDARD, MODULAR GPS RECEIVER
  - COST EFFECTIVE
  - SUPPORTS MULTIPLE PROGRAMS
  - CONFIGURABLE TO SPECIFIC APPLICATION
  - INCLUDE TESTABILITY AS DESIGN REQUIREMENT
- CONDUCT TRADE STUDY OF TECHNIQUES TO ACCOMPLISH AUTOLAND, INCLUDING A FLIGHT DEMONSTRATION
- CONDUCT TRADE STUDY OF TECHNIQUES TO PERFORM AUTONOMOUS NAVIGATION, BY MISSION PHASE, FOR VARIOUS TRANSPORTATION PROGRAMS
  - ASCENT - ORBIT - REENTRY
- CONDUCT TRADE STUDY OF TECHNIQUES FOR GPS DETERMINATION OF VEHICLE ATTITUDE, INCLUDING A FLIGHT DEMONSTRATION

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SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
FLIGHT ELEMENTS
ADVANCED AVIONICS ARCHITECTURE

NOVEMBER 1989

TECHNOLOGY ISSUES:

INTERCONNECTION TOPOLOGY

THROUGHPUT OVERHEADS
- PARALLEL COMPUTATION
- INFORMATION TRANSFER
- FAULT TOLERANCE

SOFTWARE
- OPERATING SYSTEM
- REDUNDANCY MANAGEMENT

QUANTIFIABLE PERFORMANCE AND RELIABILITY

VALIDATION METHODOLOGY

LOW POWER/SMALL FEATURE SIZE/RADIATION HARDNESS

CANDIDATE PROGRAMS:

LUNAR/MARS INITIATIVE

NASP

FUTURE AUTONOMOUS SPACECRAFT

MAJOR ACCOMPLISHMENTS:

RECOGNITION OF THE NEED FOR SUCH SYSTEMS.

SIGNIFICANT MILESTONES:

91	92	93	94	R & D BASE				
		93	94	95	96	ADV. DEVEL.		
				95	96	97	98	FLIGHT SYSTEM

718

530642

24p

PRESENTATION 2.3

N91-17031

PAYLOAD ACCOMMODATIONS

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
PAYLOAD ACCOMMODATIONS
AVIONICS PAYLOAD SUPPORT ARCHITECTURE

TECHNOLOGY ISSUES/TRADE STUDIES

DEGREE OF NASA/USER SEPARATION
- MISSION SUCCESS/SAFETY/COMPUTER SECURITY
- CONTROL OF RESOURCES (PWR, COOLING, ETC.)
- STANDARDIZATION OF INTERFACES (D&C, GUIDELINES)
- COMMON SERVICES (NASA, CENTRALIZED) VERSUS UNIQUE SERVICES (USER, DISTRIBUTED)

RELIABILITY/REDUNDANCY RELATIVE TO MISSION SUCCESS/SAFETY

NSTS: CAPABILITY TO PROVIDE U/L, D/L SERVICES TO PAYLOADS USING PGSC (MODEM, I/F TO STS COMM SYSTEM)
- CONNECTOR/CABLING VOLUME AND WEIGHT

SSF: INTEGRATION OF EXISTING AVIONICS TECHNOLOGIES TO CONTROL MULTIPLE REAL-TIME SYSTEMS.
- COST/POWER REDUCTION TO MEET BUDGETARY CONSTRAINTS.

LUNAR MARS:
- AUTOMATION/EXPERT SYSTEMS CAPABILITY
- DATA STORAGE CAPABILITY
- DEGREE OF PRETRANSMISSION PROCESSING-CUSTOMER CONCERN

CANDIDATE PROGRAMS

- NSTS ORBITER ENHANCEMENT
- SSF
- SHUTTLE-C
- LUNAR/MARS PROGRAMS
- SHUTTLE-II

MAJOR ACCOMPLISHMENTS:

- APPROACHING CONCEPT IN STS FOR SECONDARY PAYLOADS AND TSS BY UTILIZATION OF PGSC
- DISTRIBUTED PROCESSING CONCEPT BEING IMPLEMENTED IN THE STS JSC MULTIPURPOSE CONTROL CENTER (MPCC)
- ORIGINAL SSF AVIONICS DESIGN FOR PAYLOAD ACCOMMODATIONS CAPTURES MOST OBJECTIVES:
  - DISTRIBUTED PROCESSING ARCHITECTURE
  - DECOUPLE VEHICLE AND PAYLOAD SERVICES
  - STANDARDIZED TESTING, CHECKOUT, AND TRAINING
  - WITH SSF BUDGET/POWER CUTS, SOME OF THESE WILL BE COMPROMISED AT PMC BUT SYSTEM WILL BE UPGRADABLE AND WILL BE IMPROVED WITH THE FULL-UP CONFIGURATION

SIGNIFICANT MILESTONES

- DEFINITION OF THE CANDIDATE CLASSES OF PAYLOADS FOR EACH PROGRAM.
- ASSESSMENT OF PAYLOAD SERVICES FOR EACH PROGRAM RELATIVE TO COST, NEW TECHNOLOGY, RESPONSIBILITY.
- DEVELOPMENT OF PAYLOAD SUPPORT POLICY TO DISTRIBUTE RESPONSIBILITY TO THE USER WHEN PRACTICAL AND COST EFFECTIVE.
- DESIGN AVIONICS PAYLOAD SUPPORT ARCHITECTURE TO SUPPORT THE ABOVE, USING INDUSTRY STANDARDS AND WITH THE CAPABILITY FOR UPGRADES.
- PRODUCE GUIDELINES FOR USERS FOR SUCH ITEMS AS DISPLAY STANDARDIZATION TO REDUCE CREW TRAINING AND OPERATIONS.
- INCREASE IN OPS EFFICIENCY BY THE DEVELOPMENT AND APPLICATION OF NEW AVIONICS TECHNOLOGY INCLUDING AUTOMATION, ROBOTICS, EXPERT SYSTEM, VOICE RECOGNITION, SPEAKER INDEPENDENT SYSTEMS, ENHANCED VIDEO DISPLAY CAPABILITY

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
PAYLOAD ACCOMMODATION
SATELLITE SERVICING

NOVEMBER 1989

ADVANCED AVIONICS CONCEPTS

SYSTEMS INTEGRATION
- SYS. RQMTS DEF.
- TRAJECTORY CTL RQMTS
- SCENARIO ASSM'T
- PROGRAM PLANNING

GN&C DEVELOPMENT
- RELATIVE GUIDANCE
- AUTO PROX OPS
- COOP. CONTROL
- AI APPLI-CATIONS

SENSORS & MECHANISMS
- REL. NAV. SENSORS
- SENSOR TRADES
- MECHANISMS APPLICATION

MAJOR OBJECTIVES:

O DEVELOP AUTONOMOUS RENDEZVOUS, PROXIMITY OPS, & DOCKING/BERTHING CAPABILITIES FOR SATELLITE SERVICING:
- COST EFFICIENCY
- RELIABILITY
- INCREASED AVAILABILITY
- REDUCED CREW WORKLOAD

KEY CONTACTS:

S. LAMKIN/JSC
T. BRYANT/MSFC
R. SAVELY/JSC
R. LEE/TRW-HOUSTON
C. GOTT/JSC

FACILITIES:

O 6 AND 12 DOF ENGINEERING SIMULATIONS (JSC & CSDL)
O MSFC FLAT-FLOOR FACILITY
O THERMAL/VACUUM FACILITIES (JSC & MSFC)

MAJOR MILESTONES (1990 - 1995):

- DEFINE AR&D SYSTEM REQUIREMENTS (1991)
- DEVELOP SENSOR BREADBOARD (1991)
- DEVELOP VALIDATED GN&C SW (1992)
- DEVELOP PRELIMINARY DOCKING MECHANISM (1992)
- GROUND DEMONSTRATION (LATE-1992)
- FLIGHT DEMONSTRATION PLANS (1993)
- SSS AR&D DEMONSTRATION FLIGHTS
  - o DF-1: LATE 1993
  - o DF-3: 1995

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
PAYLOAD ACCOMMODATION
SATELLITE SERVICING

NOVEMBER 1989

TECHNOLOGY ISSUES:

- DEVELOPMENT OF ACCURATE RELATIVE NAVIGATION SENSORS
- DEVELOPMENT AND INTEGRATION OF GN&C TECHNIQUES (INCLUDING AI)
- SYSTEM INTEGRATION OF SENSORS, GN&C SYSTEM & DOCKING/BERTHING MECHANISM

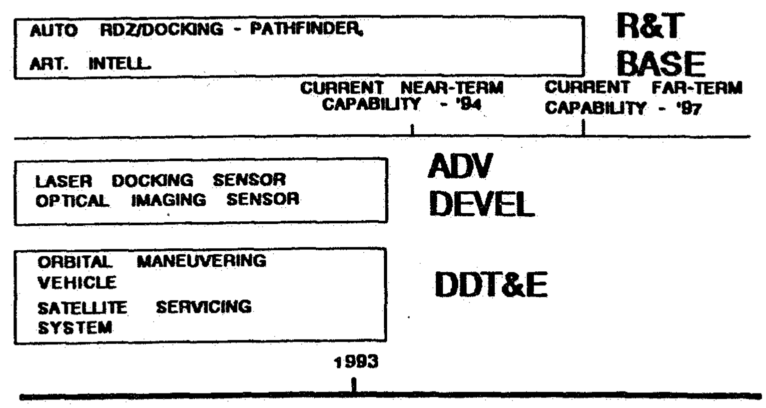
CANDIDATE PROGRAMS:

- SATELLITE SERVICER PROGRAM
- SPACE STATION
- NEXT MANNED TRANSPORTATION SYSTEM
- ASSURED SHUTTLE AVAILABILITY

MAJOR ACCOMPLISHMENTS:

- LASER DOCKING SENSOR CURRENTLY UNDER DEVELOPMENT. RELATIVE NAV CAPABILITY TO SUPPORT SSS
- AR&D PROJECT PLAN FOR PROJECT PATHFINDER HAS BEEN DEVELOPED
- SATELLITE SERVICER SYSTEM PHASE B CONTRACT IS IMMINENT
- AUTONOMOUS OPERATIONS TEST BED DEVELOPMENT (JAN 90)

SIGNIFICANT MILESTONES:



PAYLOAD ACCOMMODATION - SATELLITE SERVICING

MAJOR OBJECTIVES

- DEVELOP AND DEMONSTRATE AUTONOMOUS RENDEZVOUS, PROXIMITY OPERATIONS, AND DOCKING/BERTHING CAPABILITIES TO SUPPORT SATELLITE SERVICING

- DRIVERS FOR AUTONOMOUS RENDEZVOUS AND DOCKING
  - INCREASED RELIANCE ON UNMANNED VEHICLES
  - POTENTIAL FOR HIGHER FREQUENCY MANNED RENDEZVOUS AND DOCKING OPERATIONS

- EXPECTED BENEFITS FROM AUTONOMOUS RENDEZVOUS AND DOCKING
  - INCREASED AVAILABILITY (REDUCED OPERATIONAL CONSTRAINTS)
  - INCREASED COST EFFICIENCY (PROPELLANT, WORKLOADS)
  - MORE CONSISTENCY

PAYLOAD ACCOMMODATION - SATELLITE SERVICING

TECHNOLOGY ISSUES

- DEVELOPMENT OF RELATIVE NAVIGATION SENSORS
  - HIGH ACCURACY
  - EXTENDED OPERATING RANGE
  - LOW WEIGHT, SMALL SIZE AND LOW POWER REQUIREMENTS
- DEVELOPMENT AND INTEGRATION OF GUIDANCE, NAVIGATION AND CONTROL (GN&C) ALGORITHMS/TECHNIQUES
  - ROBUST, RELIABLE, AND ADAPTABLE
  - SAFE (CREW AND VEHICLE)
  - ACCOMMODATE CONTINGENCIES
- INTEGRATION OF SENSORS, EFFECTORS, GN&C ALGORITHMS & TECHNIQUES, AND DOCKING BERTHING MECHANISMS INTO TOTAL SYSTEM CAPABILITY

PAYLOAD ACCOMMODATION - SATELLITE SERVICING

TECHNOLOGY DEVELOPMENT APPROACH

- USE WORK BREAKDOWN STRUCTURE PATTERNED AFTER AR&D PROJECT FOR PATHFINDER (NEXT PAGE)

- PROPOSE TO ALIGN AR&D DEVELOPMENT WITH SATELLITE SERVICER SYSTEM FLIGHT DEMONSTRATIONS

  - ORBITAL MANEUVERING VEHICLE (CHASER VEHICLE)
  - SENSOR OPTIONS
  - STAGED FLIGHT DEMONSTRATIONS OF AR&D CAPABILITIES

PAYLOAD ACCOMMODATIONS - SATELLITE SERVICING

AR&D WORK BREAKDOWN STRUCTURE

SYSTEMS INTEGRATION

- SYS. RQMTS DEF.
- TRAJECTORY CTL RQMTS
- SCENARIO ASSM'T
- PROGRAM PLANNING

GN&C DEVELOPMENT

- RELATIVE GUIDANCE
- AUTO PROX OPS
- COOP. CONTROL
- AI APPLI-CATIONS

SENSORS & MECHANISMS

- REL NAV. SENSORS
- SENSOR TRADES
- MECHANISMS APPLICATION

PAYLOAD ACCOMMODATION - SATELLITE SERVICING

MAJOR MILESTONES (1990 - 1995)

- DEFINE AR&D SYSTEM REQUIREMENTS - 1991
- DEVELOP SENSOR BREADBOARD - 1991
- DEVELOP VALIDATED GN&C SOFTWARE - 1992
- DEVELOP PRELIMINARY DOCKING MECHANISM - 1992
- IMPLEMENT GROUND DEMONSTRATION - LATE-1992
- DEVELOPMENT FLIGHT DEMONSTRATION PLANS - 1993
- SATELLITE SERVICER SYSTEM (SSS) AR&D DEMONSTRATION FLIGHTS
  - DF-1: LATE 1993
  - DF-3: 1995

PAYLOAD ACCOMMODATION - SATELLITE SERVICING

CANDIDATE PROGRAMS

- NEAR-TERM FOCUS ON SATELLITE SERVICER SYSTEM FLIGHT DEMONSTRATION
- SPACE STATION
- SHUTTLE EVOLUTION
- NEXT MANNED TRANSPORTATION SYSTEM
- ASSURED SHUTTLE AVAILABILITY
- LUNAR AND MARS INITIATIVE

PAYLOAD ACCOMMODATION - SATELLITE SERVICING

MAJOR ACCOMPLISHMENTS

- LASER DOCKING SENSOR CURRENTLY UNDER DEVELOPMENT (JSC LEAD)
- OPTICAL SENSOR CURRENTLY UNDER DEVELOPMENT (MSFC LEAD)
- AR&D PROJECT PLAN FOR PATHFINDER PROJECT HAS BEEN DEVELOPED
  - MISSION SCENARIOS DEVELOPED
  - PRELIMINARY SYSTEM REQUIREMENTS DEVELOPED
  - GN&C ALGORITHMS UNDER DEVELOPMENT
  - SENSOR TRADE STUDY UNDER WAY
  - TRAJECTORY DESIGNS UNDER WAY
  - MECHANISMS BASIC RESEARCH UNDER WAY
- SATELLITE SERVICER SYSTEM PHASE B CONTRACT RFP RELEASE IS IMMINENT
- OMV DEVELOPMENT IS IN PROGRESS
- DOCKING/GRAPPLE MECHANISMS FOR SATELLITE SERVICING ARE UNDER DEVELOPMENT

PAYLOAD ACCOMMODATION - SATELLITE SERVICING FACILITIES

- 6 AND 12 DEGREE-OF-FREEDOM ENGINEERING SIMULATIONS (JSC & CSDL)
- FLAT-FLOOR FACILITIES (MSFC AND JSC)
- THERMAL/VACUUM FACILITIES (JSC AND MSFC)
- DOCKING MECHANISM TEST FACILITIES (MSFC AND JSC)

PAYLOAD ACCOMMODATION - SATELLITE SERVICING

KEY CONTACTS

JSC:

STEVE LAMKIN, PATHFINDER AR&D PROJECT MANAGER - 483-8264

CHARLES GOTT, TRAJECTORY CONTROL ANALYSIS - 483-8107

ROBERT SAVELY, ARTIFICIAL INTELLIGENCE DEVELOPMENT - 483-8105

MSFC:

THOMAS BRYANT, AUTONOMOUS RENDEZVOUS AND DOCKING DEVELOPMENT - 544-0617

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
PAYLOAD ACCOMMODATION
SATELLITE SERVICING

November 1989

Advanced Avionics Concepts

- Integrated Test Facility
  - Large Precision Flat Floor
  - Dynamic Overhead Simulator
  - Full-scale Black-out
  - Solar Illumination Simulation
  - Networked Computer Facility

Major Objectives

- Full Scale Mechanisms & Sensors
- Video, Laser, Inertial Sensor
- Dynamic Docking Approach (150')
- Multi-body Simulation
- Large Scale Manipulator Simulator
- FTS - OMV Servicer Simulation

Key Contacts

- E.C. Smith - MSFC
- Tom Bryan - MSFC

Facilities

- MSFC Flight Robotics Laboratory

Major Milestones (1990 - 1995)

• OMV Auto Dock Sensor Evaluation	Jan 1990
• Facility Extension Completion	Feb 1990
• Tumbling Satellite Retriever	Apr 1990
• Dynamic Solar Lighting Simulator	Sept 1990
• Station Module Auto Berthing Demo	1991

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
PAYLOAD ACCOMMODATION
SATELLITE SERVICING

November 1989

Technology Application Issues

- Lighting And Illumination Effects
- Guidance Sensor Realtime Performance
- Mechanism Operations

Candidate Programs

- OMV
- Space Station Berthing Mechanisms
- Flight Telerobotic Servicer
- Stabilized Payload Deployment Mechanism
- Shuttle-C Deployment
- Pathfinder Auto Guidance Development
- Lunar / Mars Vehicle Assembly

Major Accomplishments

- OMV Latch Contact Dynamics
- OMV Auto Dock Demonstration
- GE Polar Platform Auto Dock Sensor
- OMV Video Verification Tests

Significant Milestones

- Facility Extension Completion
- Dynamic Solar Lighting Simulator
- Flight Hardware Dynamic Testing Validation

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
PAYLOAD ACCOMMODATION
SATELLITE SERVICING

ADVANCED AVIONICS CONCEPTS

Tracking & Guidance Sensor with active Illumination

RMS Docking Target Augmented with retro-reflective material

MAJOR OBJECTIVES:

- Low cost
- Low complexity
- Requires only a passive target
- Capable of operating in a variety of scenarios

KEY CONTACTS

E.C. Smith/MSFC

F. Dabney/MSFC

R. Howard/MSFC

S. Lamkin/JSC

FACILITIES

MSFC Flight Robotics Laboratory

MAJOR MILESTONES (1990-1995):

- Test current technology (1990)
- Complete development of advanced applications (1991)
- Analysis and large scale hardware demonstration (1991)

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
PAYLOAD ACCOMMODATION
SATELLITE SERVICING

TECHNOLOGY ISSUES:

- Sensor range: moving parts vs. reliability
- Self-monitoring system to defect malfunctions

CANDIDATE PROGRAM:

- OMV
- Shuttle C
- Space Station
- MARS Rover-Sample Return
- Satellite Servicing

MAJOR ACCOMPLISHMENTS:

Software simulations of various docking/Berthing algorithms

Integrated large-scale hardware tests of system

Advanced algorithms developed and awaiting hardware testing

SIGNIFICANT MILESTONES:

CCD Sensor Development

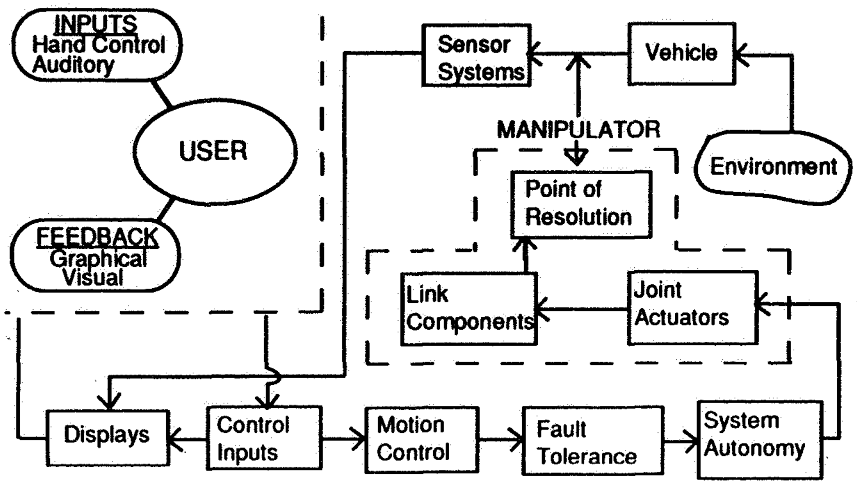
System Integration & Testing

Advanced Development

OMV SSS LUNAR/MARS

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
PAYLOAD ACCOMMODATION
P/L DEPLOY SYSTEMS & ADV. MANIPULATORS

P/L DEPLOYMENT SYSTEMS & ADV MANIPULATORS



MAJOR OBJECTIVES:

* Reduce pre-mission planning
  - Improved redundancy / fault tolerance
  - Optimal path planning
* Increase crew productivity
  - Autonomous operations frees crew for other tasks
  - Path planning / collision avoidance reduces training requirements and on-orbit planning
  - Dexterous handling reduces EVA requirements
* Increase hardware longevity
  - Load sensing / relief reduces joint / structural loads
* Reduce base vehicle attitude control system sensitivity to manipulator operations

KEY CONTACTS:

C. Gott /JSC/ FM8

D. Homan / JSC / FM8

E. Bains / JSC / EH23

J. Davidson / MMC

FACILITIES:

* Integrated Graphics and Operations Analysis Laboratory (IGOAL)
* Draper Remote Manipulator System Simulation (DRS)

MAJOR MILESTONES (1990 - 1995)

* Major programs to support
  - NSTS
  - Space Station Freedom
  - Lunar Base / Mars Mission Scenarios
* Programmatic Issues
  - Manipulator design and operations requirements
  - Integrate vehicle / manipulator control system design
  - Vehicle assembly and on-orbit processing
  - Lunar base construction
  - Mars surface operations
* Simulation development for state-of-the-art hardware & software
  - Kinematic
  - Dynamic
* Evaluate advanced technologies
* Develop systems concepts
* Evaluate capabilities / cost / benefits

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
PAYLOAD ACCOMMODATION
P/L DEPLOY SYSTEMS & ADV. MANIPULATORS

TECHNOLOGY ISSUES:

- Planning and Control Algorithm Development
  - Path planning
  - Collision avoidance
  - Redundant manipulator control
- Sensor / Effector technology
  - Dexterous manipulators / force feedback systems
  - Robotic vision / tracking
- Interaction of deployment device with vehicle control
- System performance
- System reliability

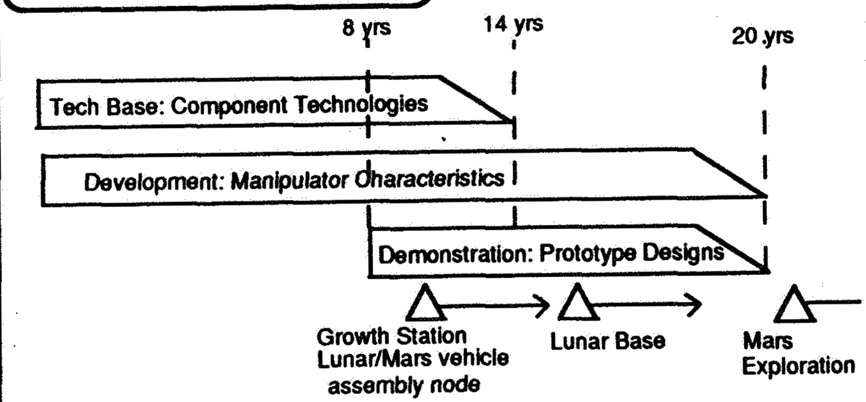
CANDIDATE PROGRAMS:

- Shuttle Remote Manipulator System
- Flight Telerobotic Servicer
- OMV
- Lunar Base
- Mars exploration
- EVA Retriever
- Special Purpose Dexterous Manipulator SPDM
- Mobile Servicing Centre

MAJOR ACCOMPLISHMENTS:

- Development of kinematic and dynamic simulators for generic remote manipulator systems and vehicle interaction
- Manipulator control law development and evaluation
- *Telepresence* systems technology investigations
  - Helmet mounted display
  - Stereoscopic vision systems
- Man-in-the-loop part task simulators
  - Shuttle Remote Manipulator System
  - Space Station Remote Manipulator System
  - Flight Telerobotic Servicer

SIGNIFICANT MILESTONES:



- Component technologies make up total manipulator system
- Robotic characteristics enhance manipulator operation and performance
- Prototype designs evolve over several generations

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM

PAYLOAD ACCOMODATION

ADVANCED TELEMETRY SYSTEMS

NOVEMBER 1989

ADVANCED TECHNOLOGIES :

1. INTEGRATED DATA SYSTEMS
2. "INTELLIGENT " SYSTEM APPROACH
3. ADVANCED SIGNAL PROCESSING
4. PAYLOAD INTERFACE TECHNOLOGY
5. DATA DISTRIBUTION PROCESSING
6. INFORMATION COMPRESSION
7. VOICE AND DATA ENCRYPTION
8. MASS DATA STORAGE
9. ADVANCED MODULATION AND CODING.

MAJOR OBJECTIVES:

PROVIDE TRANSPARENT COMMUNICATION
SUPPORT SERVICES BETWEEN PAYLOAD AND ITS USERS
COMMON TELEMETRY STANDARDS
COMMON INTERFACES
LOW COST
HANDLE DIVERSE SERVICES
PACKET AND CIRCUIT SWITCHING
INTELLIGENT DATA BASE

KEY CONTACTS:

JSC/ K. LAND, H. VANG
LeRC/ J. BAGWELL, J. HARROLD
GSFC/ D. DALTON
NMSU/ F. CARDEN, S. HORAN
JPL/ N. HERMAN, C. ELACHI

KEY FACILITIES :

JSC- FLIGHT TELECOM DEV. LAB.
LeRC- DIGITAL SYSTEMS DEV. LAB
GSFC- LASER COM. LAB
NMSU- CENTER FOR SPACE TELEM. & TELECOM. SYSTEMS

MAJOR MILESTONES:

"COMMON' SIGNAL PROCESSOR

EVOLUTION OF STANDARDS
- ENCRYPTION (COMMERCIAL)
- TELEMETRY
- COMMON INTERFACES
- COMPRESSION
- HDTV

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
PAYLOAD ACCOMODATION
ADVANCED TELEMETRY SYSTEMS

NOVEMBER 1989

TECHNOLOGY ISSUES:

1. ENCRYPTION KEY MANAGEMENT
2. UNSUPERVISED RELIABILITY
3. Gbps DATA RATES APPLICATION
4. PROTOCOL/RATE SELECTION; LEVEL OF SERVICE RENDERED
5. INTELLIGENT MULTIPLEXING
6. ONBOARD VS. DISTRIBUTED PROCESSING
7. EFFICIENT LOSSLESS COMPRESSION

CANDIDATE PROGRAMS:

- STS UPGRADES
- SPACE STATION
- ADVANCED SHUTTLE
- LUNAR/MARS EXPLORATION

MAJOR ACCOMPLISHMENTS:

- EXPERTS SYSTEM APPLICATION IN DIAGNOSTIC/ MAINTENANCE SERVICES
- NEURAL NETWORK APPLICATIONS IN COMM. MODULE DESIGNS

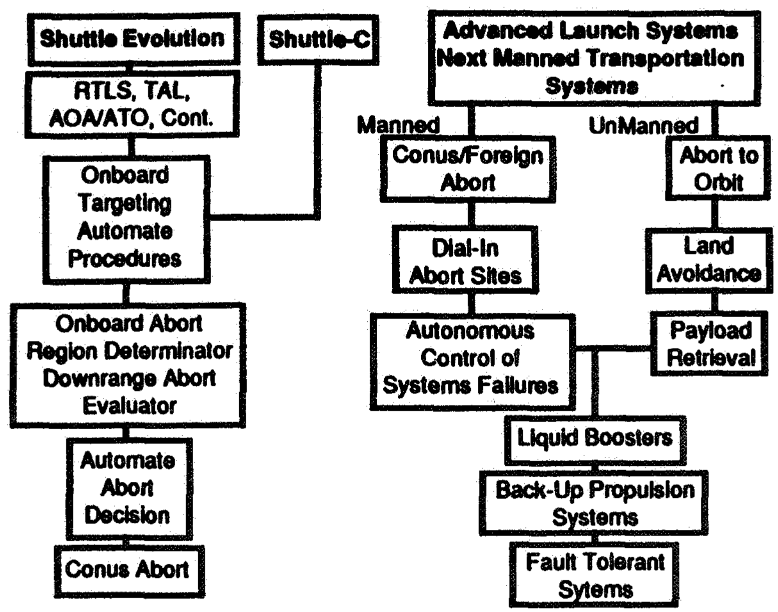
SIGNIFICANT MILESTONES:

- DEVELOPMENT OF STANDARDS FOR TRANSPARENCY
- CUSTOM SERVICES ON THE PAYLOAD ACCOMODATION TELEMETRY SYSTEM

SPACE TRANSPORTATION TECHNOLOGY SYMPOSIUM
PAYLOAD ACCOMODATIONS
ONBOARD ABORT PLANNING

NOVEMBER 1989

ADVANCED AVIONICS CONCEPTS



MAJOR OBJECTIVES

Provide Capability for:

- Single Failure Mission Completion
- Highest Probability of Vehicle, Payload and Crew Return
- Onboard Abort Decisions
- Fault Tolerant Systems
- Adaptive Control for Failures
- Onboard Targeting and Autonomous Guidance

KEY CONTACTS

- E. M. Henderson - JSC / DM
  - Richard Schmidgall
- A. J. Bordano - JSC / FM
  - McDonnell Douglas Space Systems Co.

Facilities:

- Flight Design Computational Facility - JSC / DM
  - Flight Analysis and Design System (FADS)
- MPAD Prototyping Lab - JSC / FM
- Shuttle Avionics Integration Lab (SAIL) - JSC / EA

MAJOR MILESTONES (1990-2005)

Technology Availability:

• Onboard Expert Systems	1994
• Adaptive Guidance Algorithms	1995
• Advanced Sensors	1998
• Flight Qualified Parallel Proc.	2000
• Information Management System	2002
• Advanced Onboard Man / Machine Interfaces	2002

SPACE TRANSPORTATION TECHNOLOGY SYMPOSIUM
PAYLOAD ACCOMODATIONS
ONBOARD ABORT PLANNING

NOVEMBER 1989

TECHNOLOGY ISSUES

- Liquid vs. Solid Boosters
- Automated vs. Manual Abort Techniques
- Ground vs. Onboard Abort Decision
- Development of High Density Mass Storage GPC's
- Onboard Parallel Processing for GN&C applications
- Development of Onboard Expert Systems
- Systems Enhancements to Sustain Multiple Engine Failures
  - Active CG Control
- Range Destruct vs. System Reliability

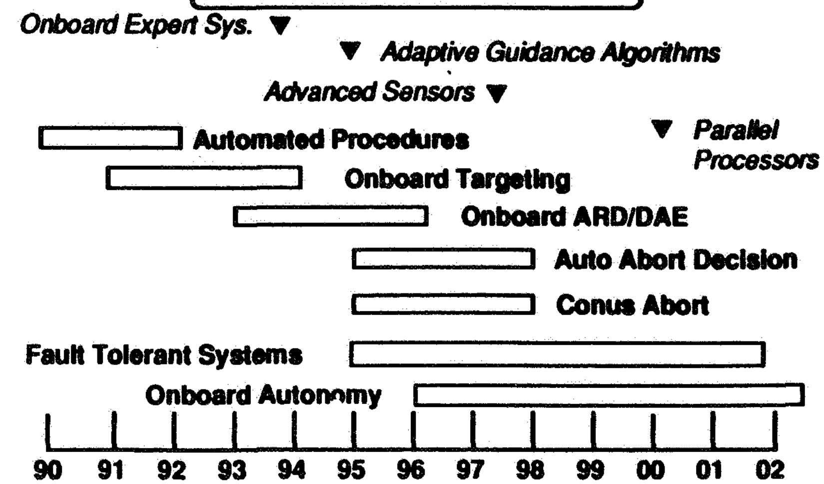
CANDIDATE PROGRAMS

- STS / STS Evolution / ASRM
- ELV'S
- STS - C
- ALS
- AMLS
- Lunar / Mars Initiative

MAJOR ACCOMPLISHMENTS

- Automation of Manual Procedures
- Onboard Abort Region Determinator / Downrange Abort Evaluator
- Dial-In Abort Sites
- Onboard Targeting and Abort Guidance
- Adaptive Guidance

SIGNIFICANT MILESTONES



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PRESENTATION 2.4

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SYSTEM ENGINEERING AND INTEGRATION (SE&I)

SE & I

SYSTEMS ENGINEERING
AND
INTEGRATION

ED CHEVERS
JOHNSON SPACE CENTER
SAM HALEY
MARSHALL SPACE FLIGHT CENTER

SE&I

- THE INFRASTRUCTURE REQUIRED FOR A SYSTEMS LEVEL APPROACH TO THE DESIGN OF AVIONIC SYSTEMS

- DEFINES THE TOP LEVEL PROCESSES AND METHODOLOGIES REQUIRED TO SUPPORT THE DESIGN, DEVELOPMENT, TEST, AND INTEGRATION OF AVIONIC HARDWARE AND SOFTWARE SYSTEMS

- INCLUDES THE DEVELOPMENT OF GENERIC TOOLS NECESSARY TO SUPPORT ALL PHASES OF DEVELOPMENT FROM CONCEPT TO FLIGHT CERTIFICATION...i.e. MODELS, CONFIGURATION MANAGEMENT, COST ESTIMATION, REAL-TIME SIMULATIONS, PRE-POST TEST DATA PROCESSING AND ANALYSIS, RISK ANALYSIS, AND QUALITY CONTROL

A CHALLENGE TO THE OTHER PANELS

- THIS SYMPOSIUM ADDRESSES THE ISSUE OF TECHNOLOGY ADVANCEMENT FOR PRESENT AND FUTURE SPACE TRANSPORTATION VEHICLES

- MUCH TO DO IN ALL MEETINGS OF THIS TYPE REGARDING TIME REQUIRED TO DEVELOP TECHNOLOGY AND CONCERN THAT SYSTEMS ARE OBSOLETE WHEN FLOWN

BUT

SO WHAT

- CHALLENGE IS TO DEVELOP SYSTEMS WHICH CAN BE EVOLVED AND IMPROVED IN SMALL INCREMENTAL STEPS WHERE EACH INCREMENT:
  - REDUCES PRESENT COST (INCREASES EFFICIENCY)
  - IMPROVES RELIABILITY/CREW SAFETY (IF THERE IS A PROBLEM)
  - DOES NEITHER OF ABOVE BUT SETS THE STAGE FOR A SECOND INCREMENTAL UPGRADE THAT DOES ACCOMPLISH ONE OF THE ABOVE

A CHALLENGE TO THE OTHER PANELS

- ISSUE

1) MAJOR UPGRADES REQUIRE LOSS OF VEHICLE FOR YEARS

2) MAJOR UPGRADES REQUIRE DUAL OPERATION OF OLD AND NEW TECHNOLOGY UNTIL CONFIDENCE ESTABLISHED

3) COST TO CHANGES IN SE&I INFRASTRUCTURE MAY BE MORE THAN "TRADITIONALLY" RECOGNIZED COST OF TECHNOLOGY UPGRADE

WHAT'S BEING DONE TODAY

- RISK ANALYSIS MANAGEMENT
- TOTAL QUALITY MANAGEMENT
- COST ESTIMATION
- COMPUTER AIDED SOFTWARE ENGINEERING
- HARDWARE/SOFTWARE LIFECYCLE METHODOLOGIES
- SYSTEM TESTABILITY
- RAPID PROTOTYPING
- ADVANCED SOFTWARE INTEGRATION
- ADVANCED TRAINING SYSTEMS
- AVIONIC SYSTEM INTEGRATION FACILITIES

WHAT'S REQUIRED IN THE FUTURE

- INTERFACE STANDARDS FOR COMMERCIAL OFF THE SHELF (COTS) PRODUCTS TO AID IN DEVELOPMENT OF INTEGRATED FACILITIES

- ENHANCED AUTOMATED CODE GENERATION SYSTEMS TIGHTLY COUPLED TO SPECIFICATION AND DESIGN DOCUMENTATION

- MODELING TOOLS THAT SUPPORT DATA FLOW ANALYSIS, RUN IN REAL TIME AND GROW WITH THE DESIGN AS IT EVOLVES

- SHARED PROJECT DATA BASES CONSISTING OF TECHNICAL CHARACTERISTICS, COST INFORMATION, MEASUREMENT PARAMETERS, AND REUSABLE SOFTWARE PROGRAMS

SE&I Topics

- Advanced Avionics Development Strategy – Dave Dyer
- Risk Analysis & Management – Ed Smith
- Total Quality Management – Ken Shipe
- Low Cost Avionics – Whitt Brantley
- Cost Estimation & Benefits – Joe Hamaker
- Computer Aided Software Engineering – Carrie Walker
- Computer Systems & Software Safety – Dr. Charles McCay
- System Testability – Tom Barry
- Advanced Avionics Laboratories – Bud Gates
- Rapid Prototyping Systems – Paul Schoen

Avionics Advanced Development Strategy

- Objective
  - Unified Strategy For Avionics Advanced Development To Meet NASA Transportation Needs
- Leverage
  - Maximum Overall Benefit From Limited Funds For Advanced Development
- Approach
  - Systematic Method To Aid Prioritization And Scheduling Of Various Proposed Avionics Technology Developments
- Issues
  - General Acceptance Of Any Systematic Approach Affecting Distribution Of Limited Funds In A Competitive Environment

Risk Analysis & Management

- Objective
  - Improved *Capabilities* For Identifying And Quantifying Risks Inherent In Avionics Systems Designs

- Leverage
  - Understanding Where To Apply Limited Funds For Best Overall System Improvement

- Approach
  - Development And Demonstration Of New Analytical Tools For Risk Analysis

- Issues
  - Tool Set Portability And Multi-program Implementations

Total Quality Management

- Objective
  - Application Of Variability Reduction Process To The Development Of Avionics Systems
- Leverage
  - Achievement Of Robust Designs, Capable Manufacturing Processes, High Reliability, And Low Cost.
- Approach
  - Development And Applications Of New Techniques For Simultaneous Engineering, Quality Function Deployment, Parameter Design, And Statistical Process Control.
- Issues

LOW COST AVIONICS

- Objective
  - Strategy For Low Cost, Reliable, Low Maintenance Avionics

- Leverage
  - Lowered User Costs Through Implementation Of Appropriate New Technologies, Production Techniques, And Operations

- Approach
  - Evaluate Innovative Ideas And Recent Experience On NASA/Military/Commercial Space Programs

- Issue
  - How To Test New Ideas And How To Deal With The Necessary Cultural Changes To Implement New Ideas

Cost Estimation Benefits Analysis

- Objective
  - Accurate Cost Analysis Of New Proposed Avionic/Software Systems

- Leverage
  - Enables Timely Program Decisions On Avionics System Design Choices Where Cost Is A Major Discriminator

- Approach
  - Investigate Better Metrics For Translating Cost Drivers Into Costs And Develop Associated Tools

- Issues
  - Updating Database, Metrics, And Tools To Be Accurate For Modern/Advanced Avionics Software Systems

Computer Aided Software Engineering

- Objective
  - New Techniques And Toolsets For Computer Aided Software Engineering
- Leverage
  - Makes Definition Development, Verification And Maintenance Of Software Systems More Productive, Robust, Cost Effective, And Adaptable
- Approach
  - Development And Application Of Artificial Intelligence And Structured Analysis Tools.
- Issues
  -

Computer Systems & Software Safety

- Objective
  - Software Systems That Are Safe And Support Mission And Safety Critical Components
- Leverage
  - Assured Probability That System Will Provide Appropriate Protection Against The Effects Of Faults Which Might Endanger Lives, Health, Property, And Environment
- Approach
  -
- Issues
  - System Cost And Complexity vs. Degree Of Safety

System Testability

- Objective
  - Guidelines And Techniques To Assure Testability Of Avionics Systems
- Leverage
  - Efficient, Low Cost Test And Checkout Operations And Greater Assurance Of System Health
- Approach
  - Development And Application Of Advanced Test/Checkout And Health Status And Monitoring Technology To Avionics Designs For Testability
- Issues
  - Cost And Complexity Of Testability Features

Advanced Avionics Laboratories

- Objective
  - Modern Multi-use Laboratories As Proving Ground For Advanced Avionics Concepts

- Leverage
  - Timely Demonstration Of New Avionics Technologies And Concepts For Program Acceptability

- Approach
  - Large Reconfigurable Laboratories With Flexibility And Availability For Sharing Between Programs

- Issues
  - Ease Of Reconfigurability To Accommodate Many Diverse And Complex Avionics Systems; And NASA Cultural Changes

RAPID PROTOTYPING SYSTEMS

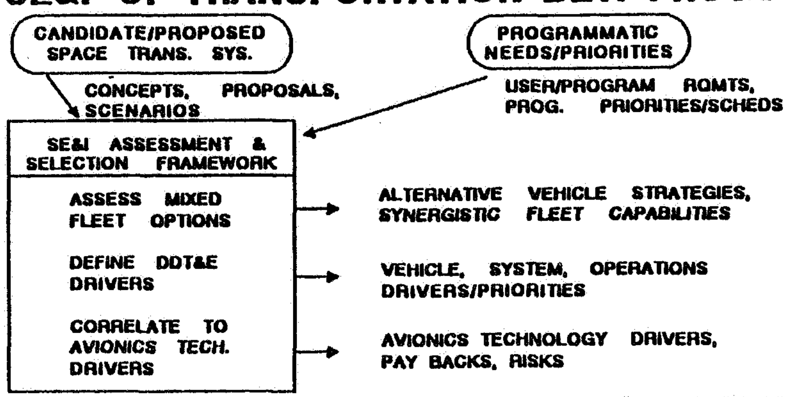
- Objective
  - Rapid Prototyping Tools To Efficiently Integrate Early System And Program Requirements Into Preliminary Designs
- Leverage
  - Provides Early Performance Measures Identifies Resource Bottlenecks, And Supports Trade Studies Of Candidate System Designs
- Approach
  - Develop And Apply Rapid Prototyping Tools To Avionics Preliminary Design And Analysis
- Issue
  - Tool Set Portability And Multi-program Acceptance And Implementation

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
SYSTEMS ENGINEERING AND INTEGRATION
AVIONICS ADVANCED DEVELOPMENT STRATEGY

NOVEMBER 1989

ADVANCED AVIONICS CONCEPTS

SE&I OF TRANSPORTATION DEV. PROGS



MAJOR OBJECTIVES:

DEVELOP FRAMEWORK FOR ASSESSING AND INTEGRATING AVIONICS ADVANCED TECHNOLOGY DEVELOPMENTS

- PRIORITY AND PHASING OF FUTURE SPACE TRANSPORTATION SYSTEMS
- INTEGRATION ACROSS MULTIPLE PROGRAMS/PROJECTS
- SELECTION/EVALUATION CRITERIA

KEY CONTACTS:

D. DYER/NASA-RESTON
K. COX/JSC

FACILITIES:

MAJOR MILESTONES (1990 - 1995):

O ASSIMILATE RESULTS/STATUS OF VARIOUS SPACE TRANSPORTATION SYSTEM STUDIES (MID TO LATE 90)
- MANNED SPACE TRANSPORTATION
- LUNAR/MARS EXPLORATION INITIATIVE
- CERV, EXT. DURATION ORBITER

O DEVELOP INITIAL FRAMEWORK FOR ASSESSING/PRIORITIZING TECH. NEEDS (MID FY 90)

O APPLY FRAMEWORK (FY 91)

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
SYSTEMS ENGINEERING AND INTEGRATION
AVIONICS ADVANCED DEVELOPMENT STRATEGY

NOVEMBER 1989

TECHNOLOGY ISSUES:

- O INTEGRATION OF TRANSPORTATION NEEDS
- O STANDARD, PRE-DECLARED CRITERIA FOR ASSESSING:
  - FLEET OPTIONS
  - DESIGN DRIVERS
  - TECHNOLOGY FOCUS
- O SYSTEMATIC ASSESSMENT OF SENSITIVITIES OF OPTIONS & CORRESPONDING RISKS (TECH/PROG)

CANDIDATE PROGRAMS:

- O MANNED TRANSPORTATION SYSTEMS
  - SHUTTLE EVOLUTION
  - CERV
  - MANNED MARS/LUNAR MISSIONS
- O UNMANNED TRANSPORTATION SYS
  - OMV
  - OTV
  - MARS/LUNAR MISSIONS

MAJOR ACCOMPLISHMENTS:

- O MRSR PHASE B STUDIES UNDER WAY
- O MANNED SPACE TRANSPORTATION STUDY/DEFINITION UNDER WAY
- O LUNAR/MARS EXPLORATION INITIATIVE UNDER WAY

SIGNIFICANT MILESTONES:

NASA
National Aeronautics and
Space Administration

FREEDOM

Space Transportation Avionics Technology Symposium

Williamsburg, Virginia

Avionics Advanced Development Strategy

D. Dyer, JSC/TDY SSFPO Reston
SE&I Subpanel
November 7-9, 1989

NASA
National Aeronautics and
Space Administration

FREEDOM

Introduction

- Collected technology needs from individual programs/vehicles
- Bottoms-up collection of proposed advanced development items
- Result is not necessarily a match and usually not affordable

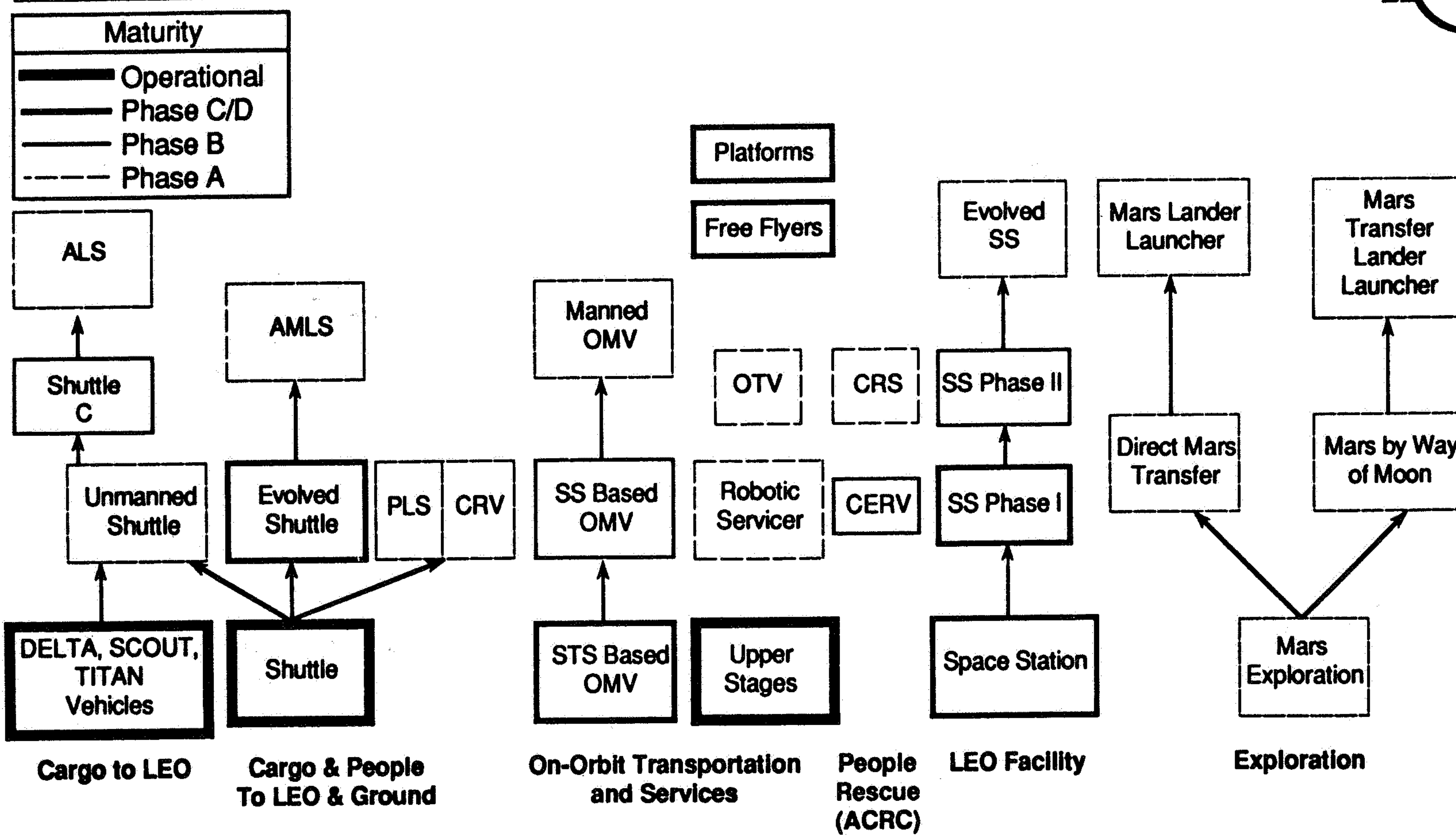
Problem

How to put together an integrated, phased, and affordable advanced development program that links operational, evolving, and developing programs/vehicles as-well-as those in the planning phases?

NASA
National Aeronautics and Space Administration

Scope of Transportation Needs and Maturities

FREEDOM



Scope

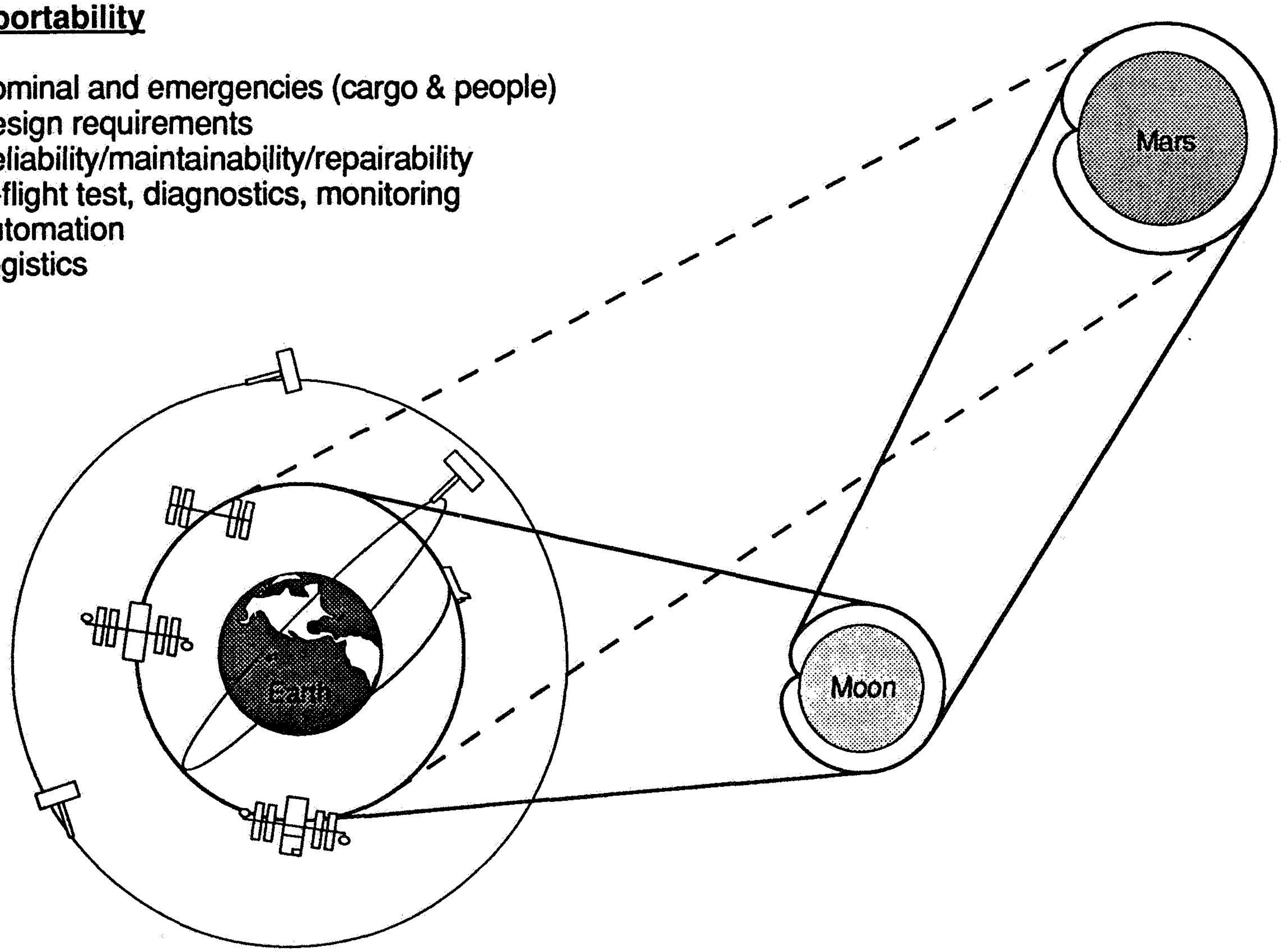
NASA
National Aeronautics and
Space Administration

Mixed Fleets Operations

FREEDOM

Supportability

- Nominal and emergencies (cargo & people)
- Design requirements
- Reliability/maintainability/repairability
- In-flight test, diagnostics, monitoring
- Automation
- Logistics



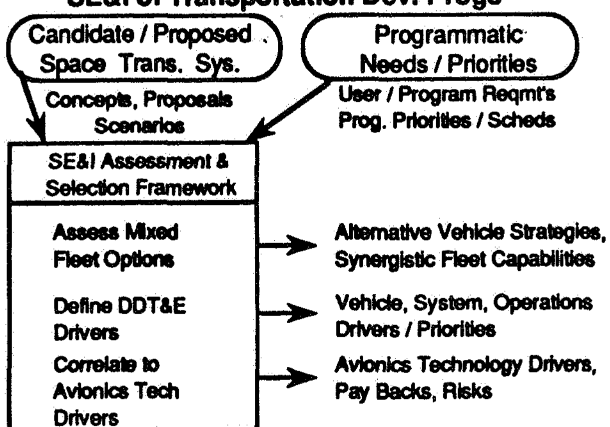
National Aeronautics and Space Administration

Space Transportation Avionics Technology Symposium
Systems Engineering and Integration
Avionics Advanced Development Strategy

November 1989

FREEDOM

Advanced Avionics Concepts



Major Objectives

Develop framework for assessing and integrating avionics advanced technology developments

- Priority and phasing of future space transportation systems
- Integration across multiple programs/projects
- Selection/Evaluation criteria

Key Contacts:

D. Dyer/NASA–Reston
K. Cox/JSC

Facilities:

Major Milestones (1990 – 1995)

- **Assimilate results/status of various transportation systems studies (Mid to late 90)**
  - Manned Space transportation
  - Lunar/Mars exploration initiative
  - Cerv, ext. duration orbiter
- **Develop initial framework for assessing/prioritizing tech. needs (mid FY 90)**
- **Apply framework (FY 91)**

Space Transportation Avionics Technology Symposium
Systems Engineering and Integration
Avionics Advanced Development Strategy

NASA
National Aeronautics and Space Administration

November 1989

FREEDOM

Technology Issues

- Integration of transportation needs
- Standard, pre-declared criteria for assessing:
  - Fleet options
  - Design drivers
  - Technology focus
- Systematic assessment of sensitivities of options & corresponding risks (Tech/Prog)

Candidate Programs

- Manned transportation systems
  - Shuttle evolution
  - CERV
  - Manned Mars/Lunar Missions
- Unmanned transportation Sys
  - OMV
  - OTV
  - Mars/Lunar Missions

Major Accomplishments

- MRSR Phase B studies under way
- Manned space transportation study/definition under way
- Lunar/Mars exploration initiative under way

Significant Milestones

NASA
National Aeronautics and Space Administration

Key Steps to Strategy Development

FREEDOM

- Identify and establish candidate/proposed space transportation system concepts, proposals, and scenarios
- Identify programmatic needs and priorities (user/program requirements, program priorities/schedules)
- Assess mixed fleet operations to determine alternative vehicle strategies and synergistic fleet capabilities
- Define DDT&E drivers and priorities (vehicle, system, operations)
- Correlate to avionics technology drivers, define paybacks and risks
- Establish selection/evaluation criteria

For example:

- Timing requirements
- Flight testing requirements
- Greatest payback across programs

NASA National Aeronautics and Space Administration

Examples of Across Program Functional Types

FREEDOM

INFLIGHT MAINTAINABILITY FOR LONG DURATION MISSIONS

- NSTS - To Support Extended Duration On-orbit (EDO)
- SSF - External and internal maintenance and logistics
- CERV - Long-term dormant avionics with quick activation
- Mars Transfers - To support functional availability and redundancy

INFLIGHT CREW TRAINING

- NSTS - To support landings after an EDO
- SSF - To support Phase II and growth station operations
- Mars - To support landings after long transfer times

AUTOMATIC RENDEZVOUS AND DOCKING

- NSTS - Unmanned flights
- SSF - To support man tended free flyer return to station
  - To support OMV/platform return to station
  - To support unmanned resupply
- OMV - To support approaches to orbiter, platforms, and satellites
- Mars - To support Mars sample return mission

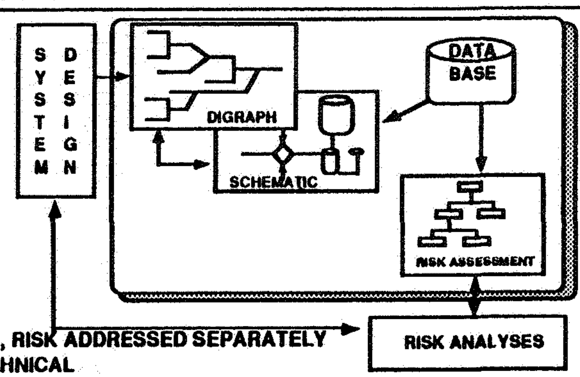
SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM

SE & I

RISK ANALYSIS & MGT

NOVEMBER 1989

SYSTEMS RISK ASSESSMENT/ANALYSIS METHODOLOGY:



PRESENTLY, RISK ADDRESSED SEPARATELY
- TECHNICAL
- SAFETY/RELIABILITY

PRESENT APPROACH PROHIBITIVE
- SYSTEM COMPLEXITY
- EXTENDED EVOLUTIONARY LIFECYCLE

MAJOR OBJECTIVES:

- COMBINE RISK METHODOLOGY
- COST-EFFECTIVE APPROACH
  - UNDERSTAND SYSTEM IN FAILURE SPACE
  - DESIGN KNOWLEDGE CAPTURE
  - SUPPORT
    - DESIGN DECISIONS
    - TEST OPERATIONS
    - FLIGHT OPERATIONS
    - TRAINING
  - PROVIDE CAPABILITY TO DEFINE AND ASSESS RISK
    - INPUT FOR QRA
    - INPUT FOR APPROPRIATE COMPONENT/UNIT ANALYSES

KEY CONTACTS:

- JT EDGE/NASA-JSC/EH3
  - PROTOTYPE TOOLS
- W. GEISSLER/LESC
  - PROTOTYPE TOOLS
- I. SACKS/R & D ASSOC.
  - DIGRAPH MATRIX ANALYSIS
- R. ROBITALLE/ROCKWELL-DNY
  - SHUTTLE CRITICAL FUNCT. AUDIT
- G. HENNING/LESC
  - FAILURE-SPACE MODELING
- J. WELLS/LLNL
  - RISK ANALYSIS TECHNIQUES
- B. BUCHBINDER/NASA HQS/Q
  - NASA RISK ANALYSIS POINT-OF-CONTACT

MAJOR MILESTONES:

- PROCESS REQUIREMENTS DEFINITION
  - 1 - 6/90
- TOOL PROTOTYPING
  - 7/90 - 8/91
- METHODOLOGY VALIDATION/DEMO
  - 9/91

C5

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
SE & I
RISK ANALYSIS & MGT

TECHNOLOGY ISSUES:

- UNDERSTANDING USER NEEDS AND EVOLVING METHODOLOGY
- METHODOLOGY ACCEPTANCE BY USERS
- TOOL PORTABILITY/FLEXIBILITY ACROSS COMPUTER SYSTEMS
- ANALYSIS TOOL INTEGRATION INTO MAJOR PROGRAM TOOLSETS
- EASE OF APPLICATIONS DEVELOPMENT AND OPERATIONS
- MODEL VALIDATION
- PROGRAM ACCEPTANCE OF IMPLEMENTATION AND MAINTENANCE COSTS

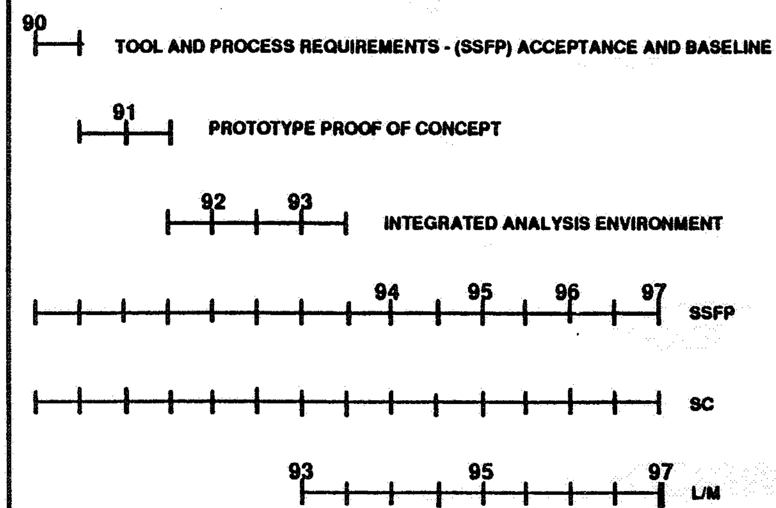
CANDIDATE PROGRAMS:

- SSFP (JT EDGE)
- LUNAR/MARS EXPLORATION
- SUPERCONDUCTING SUPERCOLLIDER (H. E. SMITH)
- NSTS (R. ROBITAILLE (SCFA))
- ASSURED CREW RETURN VEHICLE

MAJOR ACCOMPLISHMENTS:

- SHUTTLE CRITICAL FUNCTION AUDIT (SCFA)
    - DIGRAPH MODELING/TOOL DEVELOPMENT
- FIRM PROCESSOR
    - FAILURE ANALYSIS ALGORITHM-BETA TEST
- DMA WITH GRAPHICS INTERFACE
    - FAILURE ANALYSIS TOOL WITH GRAPHICS I/O
- FAILURE ENVIRONMENT ANALYSIS TOOL (FEAT)
    - FAILURE ANALYSIS TOOL WITH GRAPHIC I/O-BETA TEST
- SHUTTLE CONFIGURATION ANALYSIS PROGRAM (SCAP)
    - OPERATIONAL FAILURE ANALYSIS

SIGNIFICANT MILESTONES:



SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
SE&I
TOTAL QUALITY MANAGEMENT

NOVEMBER 1989

CONCEPTS:

- CUSTOMER SATISFACTION
- CONSTANCY OF PURPOSE
- CONTINUOUS IMPROVEMENT
- PARTICIPATIVE MANAGEMENT
- PEOPLE EMPOWERMENT / INVOLVMENT
- CONCURRENT ENGINEERING
- UNIVERSAL QUALITY MEASURES
- EDUCATION AND TRAINING

MAJOR OBJECTIVES:

1 YR — SHORT RANGE

- NATIONAL AWARENESS & COMMITMENT

3 YRS. — MID RANGE

- ESTABLISH AS A WAY OF LIFE

3-7 YRS — LONG RANGE

- USA PRODUCTS BENCHMARKED AS WORLD CLASS

KEY CONTACTS:

- K. SHIPE/ MARTIN MARIETTA ASTRONAUTICS
  (303) 971-9522
- R. SAPP / LOCKHEED
  (818) 712-2000
- M. LOFTON / MDAC-MDSSC
  (714)896-2621
- F. DOHERTY / OASD(P&L)
  (202) 695 -7915

MAJOR MILESTONES (1988-95)

- PROPOSED RULES FIRST ENTERED IN FEDERAL REGISTER, VOL. 54, NO. 137 WEDNESDAY, JULY 19, 1989
- PROPOSED AMENDMENT TITLE 32, SUBCHAPTER M, CHAPTER I ADD TQM TO PART 281 (TBD)

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
SE & I
TOTAL QUALITY MANAGEMENT

NOVEMBER 1989

TECHNOLOGY ISSUES:

- CONCURRENT ENGINEERING
- QUALITY FUNCTIONAL DEPLOYMENT
- QUALITY BY EXPERIMENTAL DESIGN
- UNIVERSAL QUALITY LANGUAGE (THE SIGMA)
- OPTIMIZATION OF PRODUCT PARAMETERS TO PROCESS CAPABILITIES
- STATISTICAL PROCESS CONTROL
- INTEGRATE R & M ANALYSIS INTO CAE
- MONETARY LOSS FUNCTION
- CALS INITIATIVES

CANDIDATE PROGRAMS:

- SPACE STATION (NASA)
- ADVANCED LAUNCH SYSTEMS (DOD & NASA)
- PROPOSED- EXTERNAL TANKS AS SPACEPORTS
- EXISTING ELV DESIGNS- TITAN , ATLAS, DELTA, SCOUT (DOD & NASA)
- FLIGHT TELEROBOTIC SERVICER (NASA)
- ZENITH STAR (DOD/SDIO)
- ALL NEW ACQUISITIONS AFTER "TBD" DATE (ALL USA AGENCIES)

MAJOR ACCOMPLISHMENTS :

- TQM RECORDED IN NATIONAL REGISTER - JULY, 1989
- FIRST NATIONAL TOTAL QUALITY MGMT. SYMPOSIUM (AIAA/ADPA/NSIA), NOV. 1989
- OVER 25 MAJOR COMPANIES HAVE BUILT THEIR "CASE FOR CHANGE" & BEGUN ISSUING INTERNAL TQM GUIDELINES - 1989

SIGNIFICANT MILESTONES:

- FIRST NASA EXCELLENCE AWARD - 1986
- MALCOLM BALDRIGE QUALITY AWARD - 1988
- NASA ESTABLISHED NINE UNIVERSITY ENGINEERING RESEARCH CENTERS - 1988
- DOD RELEASED TQM GUIDE, FINAL DRAFT, DOD 5000.51G, AUG. 1989

SPACE TRANSPORATION AVIONICS TECHNOLOGY SYMPOSIUM
SE&I
LOW COST AVIONICS

NOVEMBER 1989

LOW COST AVIONICS CONCEPTS

With:

- Consolidated Subsystems, Reduced Boxes
- Lower Levels of Distributed/Embedded Processing
- Hardware Improved Rather Than Software Redundancy Mgt.
- Software Standardization (ADA)

MAJOR OBJECTIVES

- Have Modern Low Cost Avionics Systems in Lab Demo Before Project øC/D
- Designed For Low Cost Operations
  - Ground
  - Space Based
- Designed For Continuous Change/Upgrade
- Multi-Project Applicability
- Product improvement Continually in Progress
- Commonality of Systems Across Agencies

KEY CONTACTS:

LaRC - C. Meissner, F. Pitts

MSFC - W. Clubb, W. Brantley

JSC - T. Barry, T. Moore

LaRC - H. Wimmer

WDRC - J. Stanley, R. Bortner

BAC - D. Johnson

GD - J. Karas

MMC - R. Gates

MDAC - E. Whitehead

Facilities

- MSFC Avionics Productivity Center
- JSC Avionics Eng. Lab
- Prime Contractor Labs

MAJOR MILESTONES (1990-1995):

- Developed System Lab Demos ('92-'93)
- Shuttle C Avionics ('94-'95)
- Shuttle Upgrade (95)
- ALS Avionics ('98)
- CERV, PLS ('95-98)
- TRANSER/Excursion Vehicles ('95)

SPACE TRANSPORATION AVIONICS TECHNOLOGY SYMPOSIUM
SE&I
LOW COST AVIONICS

NOVEMBER 1989

TECHNOLOGY ISSUES:

- Architectures to optimize HW/SW Integration
- Standardization of Modules/Interfaces/Back planes
- On-Board Checkout/BIT
- Assemblies with Internal Redundancy of Critical Functions
- Utilize Very Large Scale Integration on a Chip
- Improve Software Generation/Verification Techniques

CANDIDATE PROGRAMS:

- All Existing & Advanced Space Transportation Systems

MAJOR ACCOMPLISHMENTS:

- TITAN IV/ Centaur Upgrades

SIGNIFICANT MILESTONES

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM

SE&I

COST ESTIMATION & BENEFITS

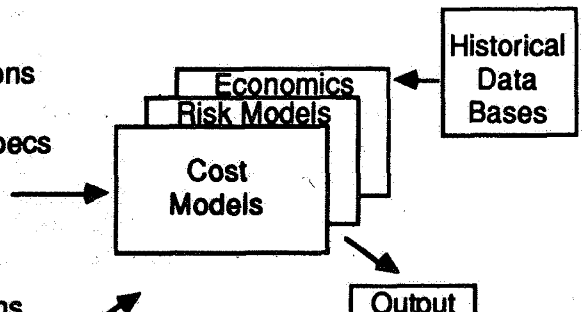
November 1989

Cost Estimation & Benefits Analysis

Input

Hardware Descriptions
- Weights
- Functional Specs
- Quantities
- Heritage
- Complexity

Software Descriptions
- Functions
- KSLOCS
- Heritage
- Complexity



Output
- Life Cycle Costs
- Sensitivities
- Confidence Levels
- Discounted Benefits

Major Objectives

- More Accurate Cost Estimates At All Phases Of Definition
- Improved Differentiation Between Competing Concepts
- Better Quantification Of Cost Drivers
- Better Metrics To Translate Cost Drivers Into Cost
- Improved Measurement Of Cost Sensitivities To Key Design And Performance Variables
- Better Quantification Of Risk / Confidence Of Estimates
- Improved Quantification / Display / Communications Of Cost Versus Benefits To Management
- Decrease Reliance On Subjective Judgements
- Wedding Of CAD / CAM / CIM / COST
- Parametric Cost / Schedule / System Performance Trades

Key Contacts

- Ed Dean / LaRC
- Ernie Fridge / JSC
- Joe Hamaker / MSFC

Major Milestones (1990 - 1995)

- JSC Software Model (1988 IOC)
- JSC AMCM Hardware Model (1989 IOC)
- LaRC AMCM & GE Price Research (1987 - ∞)
- MSFC NASCOM Model (1990 IOC)

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM

SE&I

COST ESTIMATION AND BENFITS ANALYSIS

November 1989

Technology Issues

- Realtime Collection / Analysis / Understanding Of The Data Base
- Development Of Accurate Hardware And Software Metrics
- Development Of User Friendly, Standardized Cost Models And Expert System
- Estimate Of New Technology / Languages Costs
- Accurate Software Sizing

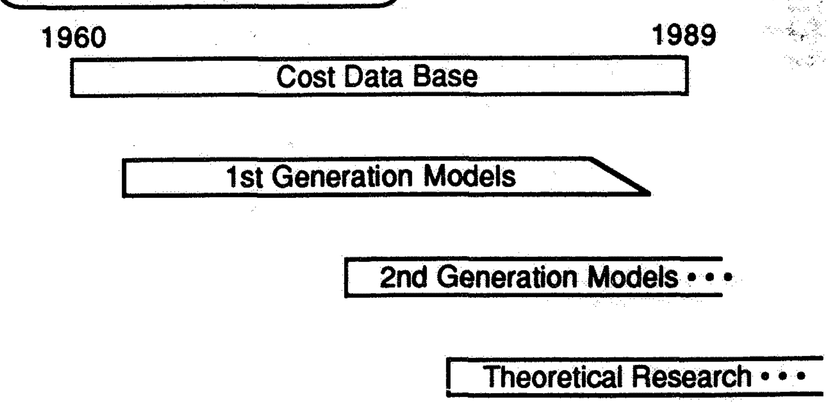
Candidate Programs

- Shuttle-C
- Advanced Launch System
- Next Manned Transportation System
- Shuttle Improvements
- Space Station Freedom
- Lunar / Mars Initiative
- All Other New Start Candidates

Major Accomplishments

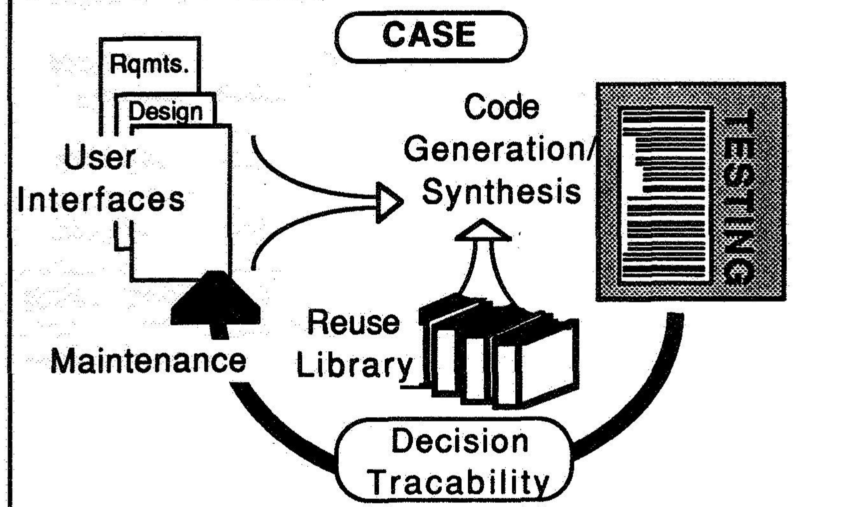
- 30 Years Of Data
- Many 1st Generation Models (1965 - 1985)
- A Few 2nd Generation Models (JSC Software Model, JSC AMCM, MSFC NASCOM, GE Price)
- Initiative Of Theoretical Research Within The Field Of Cost Analysis

Significant Milestones



SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
SYSTEMS ENGINEERING & INTEGRATION
COMPUTER-AIDED SOFTWARE ENGINEERING

NOVEMBER 1989



MAJOR OBJECTIVES:

- Rapid Software Development
- Reduced Development/Maintenance Costs
- Flexible Mission Services
- Increased Software Reliability
- Reusability
- Evolvability

KEY CONTACTS:

C. Walker/LaRC
G. Raines/JSC

MAJOR MILESTONES (1990-1995):

- Identify appropriate state-of-the-art systems (commercial or government furnished) to provide the design surface. (1990)
- Provide code generation for various architectures (hide arch. from sw developer.) (1992)
- Automate code testing. (1993)
- Integrate knowledge-based reusable software system into CASE environment. (1994)

COMPUTER-AIDED SOFTWARE ENGINEERING

TECHNOLOGY ISSUES:

- Defining software requirements clearly and unambiguously.
- Translating specification to code easily and correctly.
- Testing code for reliability.
- Maintaining code effectively.
- Managing projects efficiently.
- Applying automated methods to real-time, fault-tolerant software.
- Adapting technology to large, complex projects.

CANDIDATE PROGRAMS:

SSF
DoD
Shuttle
ELVs
ALS

MAJOR ACCOMPLISHMENTS:

- Integration of automated development techniques with knowledge-based reusable software system.

- Integration of automated development techniques with decision-tracking system.

CURRENT TECHNOLOGY:

- Slow manual code generation.
  (7-8 lines/day - flight software)

- Inefficient manual code maintenance.

- Independent handling of project design, coding, testing, maintenance, and management.

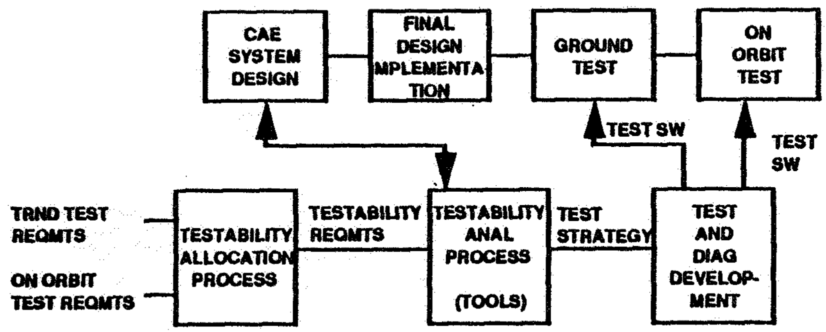
SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM

SE & I

SYSTEM TESTABILITY

NOVEMBER 1989

ADVANCED CONCEPTS:



MAJOR OBJECTIVES:

- OPTIMIZE TESTABILITY DESIGN PROCESS
- OPTIMIZE SYSTEM SUPPORTABILITY/AVAILABILITY
- PROVIDE ANALYTICAL TOOLS TO DEVELOP TEST STRATEGIES
- OPTIMIZATION OF FD/FI DESIGN
- MINIMIZE WEIGHT AND POWER OF BITE
- TESTABILITY PROCESS/TOOLS NOW MATURE
  - WIDELY USED BY DoD
  - NEED TO GET PROCESS/TOOLS INTO NASA MAINSTREAM

KEY CONTACTS:

B. ROSENBERG - HARRIS CORP
B. KELLEY - HARRIS CORP
W. KEINER - NAVY SURFACE WEAPON CENTER
J. T. EDGE - NASA JSC
R. CACERAS - MDC
H. MORROW - IBM
M. BATTAGLIA - NASA RESTON
D. LANDWEIR - IBM
J. KLION - ROME AIR DEV. CENTER
A. STANLEY - ROCKWELL AUTONETICS
J. BUCCHE - GRUMMAN
E. FREDDOLINO - ROCKWELL, DOWNEY

MAJOR MILESTONES 1990-1995

- SPACE STATION TESTABILITY PROCESS/TOOLS IN PLACE PRIOR TO PDR
- TESTABILITY PROCESS BEING USED ON LHX/ATF 1991
- APPLY TOOLS TO SHUTTLE UPGRADES 1991
- PROOF OF CONCEPT ON NASA SYSTEM 1990
- IMPROVE TESTABILITY PROCESS/TOOLS WITH TECHNOLOGY DEVELOPED BY AI/EXPERT SYSTEMS TECHNICAL DISCIPLINES

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
SE & I
SYSTEM TESTABILITY

NOVEMBER 1989

ISSUES:

- TIMELY ACCEPTANCE BY SYSTEM DEVELOPERS
- LACK OF NASA APPLICATION/PROOF OF CONCEPT
- HOW MUCH TESTABILITY IS ENOUGH
- QUANTITATIVE RELATIONSHIP OF TESTABILITY AND AVAILABILITY
- NON UNIFORMITY OF CAE TO TESTABILITY TOOLS INTERFACES
- TOOL USER FRIENDLINESS

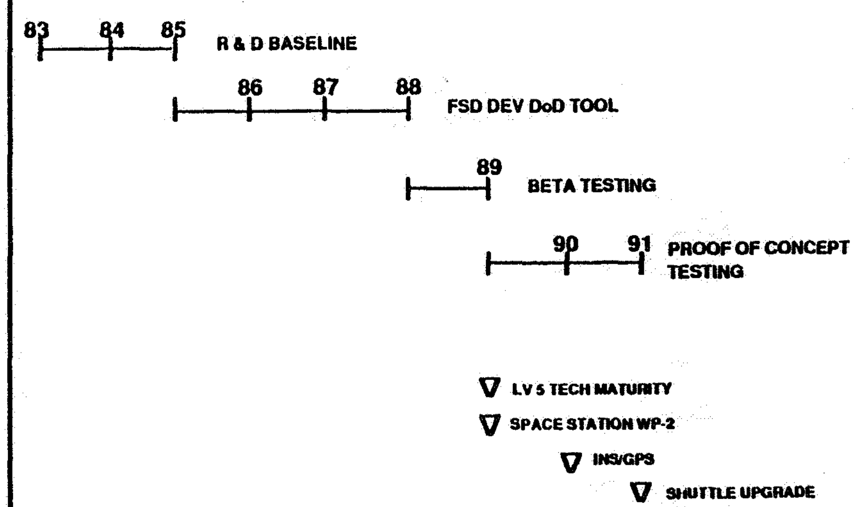
CANDIDATE PROGRAMS

- SPACE STATION - UNDERWAY
- CERV - CRITICAL FACTOR FOR VEHICLE CHECK-OUT/ AVAILABILITY
- SHUTTLE-C - REDUCE LAUNCH CHECK-OUT COST
- ALS - REDUCE LAUNCH CHECK-OUT COST
- SDI
- LUNAR MARS EXPLORATON - VISABILITY INTO SYSTEM AVAILABILITY

MAJOR ACCOMPLISHMENTS:

- BETA TEST (10 SITES) OF DoD TESTABILITY TOOL COMPLETED (1989)
- INDUSTRY BRIEFED ON DoD TESTABILITY OBJECTIVES (1988)
- MIL SPEC 2165 TESTABILITY SPEC INVOKED ON ALL NEW DoD FSD PROGRAMS (1985)

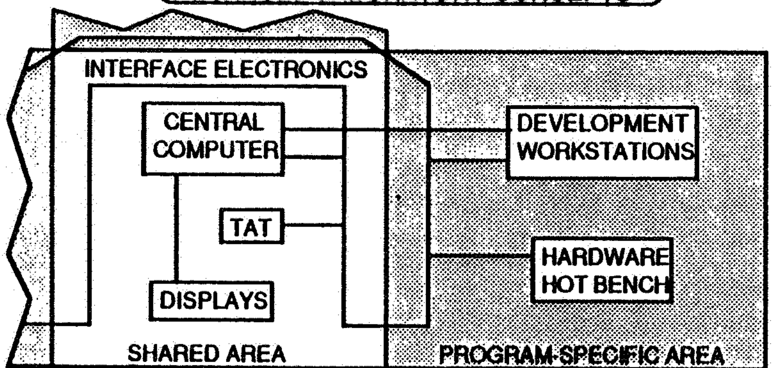
SIGNIFICANT MILESTONES:



SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
SYSTEMS ENGINEERING AND INTEGRATION
ADVANCED AVIONICS LABORATORIES

NOVEMBER 1989

ADVANCED LABORATORY CONCEPTS



SHARED AREA
- IMU Cal, test, and eval
- HWIL Simulation
- Data acquisition, logging, and display

PROGRAM SPECIFIC AREA
- Software development
- Subsystem development and simulation
- "Hot Bench"

MAJOR OBJECTIVES

- Provide a proving ground for advanced avionics concepts (Fault Tolerance, AGN&C, advanced sensors, integrated VHM)
- Reduce development and V&V costs via:
  - common hardware and facilities
  - commonality of software models and database structures
  - reduced manpower requirements for operational support
  - more efficient operations
- Provide a common development environment to encourage data sharing between programs
- Provide growth path for adaptation to new technologies

KEY CONTACTS AND FACILITIES

<u>Contacts</u>
Chuck Meissner, Felix Pitts/LaRC
Ken Cox/JSC
Ray Bortner/WRDC
Whit Brantley, Ron White/MSFC
Don Johnson/Boeing
Fred Kuenzel/GD
Crane Simmons/MDAC
Bud Gates/MMAG
Leon Shockley/RIC
Jay Lala/CSDL

<u>Government Facilities</u>
AIRLAB - LaRC
WRDC labs
MSFC labs - APC, SSME lab
JSC labs - SAIL

<u>Contractor Facilities</u>
ELV Labs at MMAG, GD, MDAC
Shuttle labs at RIC
Boeing System Integration Labs
CSDL Labs

MAJOR MILESTONES

- AIPS demos at CSDL - Oct 89
- MPRAS Demos
  - Key Concepts Mar 90
  - Subsystems Jul 91
  - Full Architecture May 92
- Shuttle-C Avionics Lab (MSFC)
  - S/W only capability Aug 90
- ALS Vehicle Avionics Simulation Laboratory (MSFC)
  - IOC Oct 91
  - Operational Aug 93

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
SYSTEMS ENGINEERING AND INTEGRATION
ADVANCED AVIONICS LABORATORIES

NOVEMBER 1989

TECHNOLOGY ISSUES

- Cultural changes necessary for acceptance of advanced avionics concepts
- Real-time hardware-in-the-loop simulation vs. all software approach
- Common database technology for multiple programs
- Providing easy transition from modeling/analysis environment to HWIL simulations
- Defining hardware and software appropriate for common areas
- Providing standalone as well as integrated testing
- Ease of reconfigurability

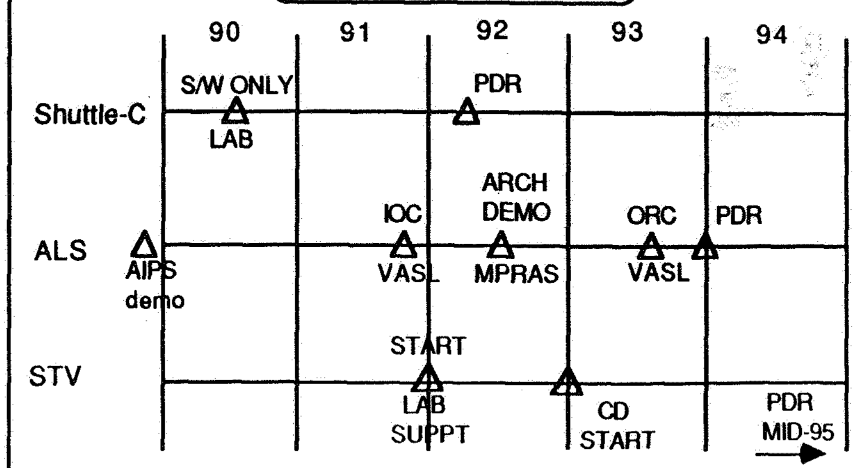
CANDIDATE PROGRAMS

- ALS
- ELV Upgrade Programs
- Shuttle
- Shuttle-C
- NASP
- Advanced upper stages (STV)
- Spacecraft programs (AXAF, others)
- Lunar/Mars Vehicles

MAJOR ACCOMPLISHMENTS

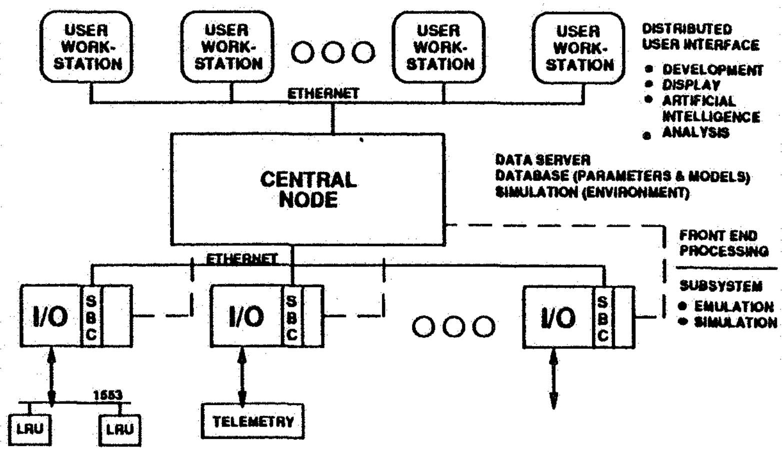
- Test, Evaluation, Integration, and Test Facility at CSDL - Oct 89
  - Supports LaRC-sponsored AIPS Distributed System
- HLCV/MAST Laboratory
  - Preliminary designs completed Feb 89
  - Concept demonstrations performed May-Sep 89

SIGNIFICANT MILESTONES



SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
SE & I ELEMENTS
RAPID PROTOTYPING SYSTEMS

RAPID PROTOTYPING SYSTEMS



MAJOR OBJECTIVES

INTEGRATED DESIGN, DEVELOPMENT, TEST AND OPERATIONS

REDUCTION IN COST - SCHEDULE, MANPOWER, RESOURCES

TRANSPORTABILITY AND REPEATABILITY OF DATA AND PROCEDURES

EARLY AVAILABILITY OF ARCHITECTURES FOR EVALUATION AND TRADE STUDIES/

REUSABILITY OF CODE

SOFTWARE ADAPTABILITY OF HARDWARE ARCHITECTURES

KEY CONTACTS

P. D. SCHOEN - AEROSPACE SIMULATION AND SYSTEMS TEST CENTER
ROCKWELL DOWNEY

T.B.D. - HONEYWELL

D. HUDSON - MARTIN MARIETTA CORPORATION

D. DEETS - DRYDEN FLIGHT RESEARCH CENTER (DFRC)

FACILITIES

NASA AND/OR CONTRACTOR FACILITIES, E.G.

AEROSPACE SIMULATION AND SYSTEMS TEST CENTER (RI/ASSTC)

SHUTTLE AVIONICS INTEGRATION LABORATORY (NASA/JSC)

REMOTELY AUGMENTED VEHICLE (RAV) FACILITY (NASA/DFRC)

MAJOR MILESTONES

OPERATIONAL SYSTEMS –

GN&C TEST STATION (GTS) RECOMMISSIONING (NASA/JSC)

ADVANCED AVIONICS TEST BED/SYSTEM (RI/DOWNEY)

REMOTELY AUGMENTED VEHICLE (RAV) FACILITY (NASA DFRC)

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
SE & I ELEMENTS
RAPID PROTOTYPING SYSTEMS

TECHNOLOGY ISSUES

STANDARDIZATION OF PROTOTYPE METHODOLOGY (PROGRAMMATIC)

- DEVELOPMENT OF RAPID PROTOTYPING APPROACH OR METHODOLOGY
- NUMEROUS, CONFLICTING VERSIONS (ANARCHY) OF APPROACHES
- LIFE CYCLE MODELS (THROWAWAY VS END PRODUCT)

DEVELOPMENT OF INTEGRATED TOOLS AND IMPLEMENTATION METHODOLOGY

- DISTRIBUTION OF PROCESSING (DATA FLOW ARCHITECTURE)
- DATA FUSION
- ADAPTIVE RECONFIGURATION
- UTILIZATION OF ARTIFICIAL INTELLIGENCE

CANDIDATE PROGRAMS

SHUTTLE/ORBITER AVIONICS EVOLUTION
ASSURED CREW RETURN VEHICLE
SHUTTLE -C
NATIONAL AEROSPACE PLANE
SPACE STATION
ADVANCED MANNED LAUNCH SYSTEM
LUNAR/MARS

MAJOR ACCOMPLISHMENTS

ESTABLISHMENT OF RAPID PROTOTYPE CAPABILITIES

- ADVANCED AVIONICS TEST BED/SYSTEM (ASSTC)
- GLASS COCKPIT DEVELOPMENT FOR NASP AND SHUTTLE/ORBITER (ASSTC)
- AUTOMATED FLIGHT TEST MANAGEMENT STUDY (AFTMS) - (NASA/DFRC)

TOOLS (EXAMPLES)

- VIRTUAL PROTOTYPING SYSTEM (VAPS)
- DISPLAY BUILDER/EDITIONS (E.G., DATAVIEWS)
- BEHAVIOR MODELING (E.G., CADNETICS)
- EXPERT CONSULTANT FOR AVIONICS SYSTEM TRANSFORMATION EXPLOITATION (ECATE)
- PROTOTYPE SYSTEM DESCRIPTION LANGUAGE (PSDL)

SIGNIFICANT MILESTONES

CENTRALIZATION OF PROTOTYPE METHODOLOGY (PROGRAMMATIC)

- SHUTTLE/ORBITER
- SHUTTLE - C
- NASP
- ALS
- AMLS

DETERMINATION OF APPROACH

- LIFE CYCLE MODEL

STANDARDIZATION OF DEVELOPMENT

- HARDWARE
- SOFTWARE (TOOLS)
- DEVELOPMENT PROCESS

STANDARDIZATION AND IMPROVEMENT OF AI TOOLS AND RESOURCES

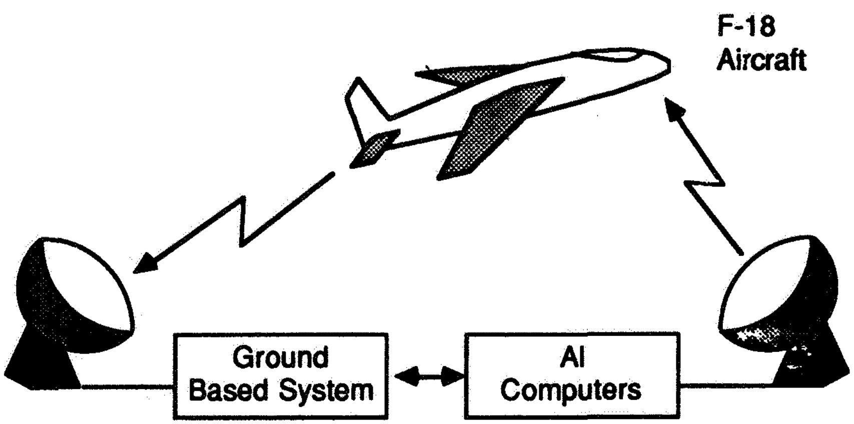
SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM

SE & I

RAPID PROTOTYPING SYSTEMS

November 1989

Rapid Prototyping Aero Demonstrations



Major Objectives

- Demonstrate New Technology Concepts In Real-World Environment
- Acceptance By Flight Operations And SR&QA Organizations
- Bring Realism To Paper Studies

Key Contacts

D. Deets/Ames-Dryden
K. Peterson/Ames-Dryden

Facilities

Rapid-Prototyping Flight Research Facility
Integrated Test Facility (IFF)
F-18 Systems Research Aircraft
CV-990 Landing Gear Research Aircraft
B-52 Launch Platform
Western Aeronautical Test Range (WATR)

Major Milestones (1990 - 1995)

• Fiber Optics Engine Sensing (F-15; F-18)	1992
• CV-990 Landing Gear Test Demonstrations	1991-93
• Transparent-Based Cockpit Display Processing (F-18)	1993

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM

SE & I

RAPID PROTOTYPING SYSTEMS

November 1989

Technology Issues:

SYSTEMS

- Real-Time Expert Systems
- Retrofit Of New Technology Into Existing Operational Vehicles
- Close Proximity Of Manned And Autonomous Unmanned Vehicles

CULTURE

- Reliance On Automation-Intensive Element In Operational Systems

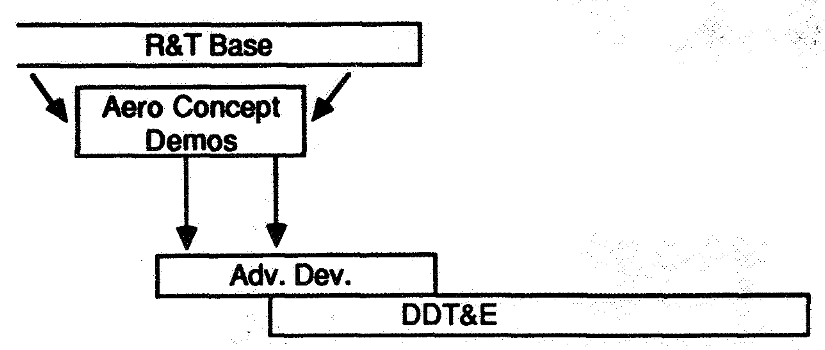
Candidate Programs

- Long-Duration Autonomous Aircraft
- Advanced Space Avionics System Retrofit In F-18 Aircraft
- Flight Planning/Monitoring Automation Demonstration
- Lifting-Body-Type Flight Research

Major Accomplishments

- F8-Digital Fly-By-Wire (1974)
- Real-Time Systems Monitoring (1987)
  - Gain And Phase Margins
  - Simulation - Flight Overlays
- Automated Flight Test Management System Demonstration (ATMS) (1988)

Significant Milestones



PANEL WHITE PAPERS

- OPERATIONAL EFFICIENCY
- FLIGHT ELEMENTS
- PAYLOAD ACCOMMODATIONS
- SYSTEMS ENGINEERING AND INTEGRATION (SE&I)

OPERATIONAL EFFICIENCY

530651
8p

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N91-17033

AUTOMATIC ASCENT FLIGHT DESIGN

WHITE PAPER ON

OPERATIONAL EFFICIENCY : AUTOMATIC ASCENT FLIGHT DESIGN

NASA JOHNSON SPACE CENTER

Mission Operations Directorate
Flight Design and Dynamics Division

Mission Support Directorate
Mission Planning and Analysis Division

JANUARY 1990

1. INTRODUCTION

The expected increase in launch vehicle operations to support Space Station Freedom and a Lunar/Mars exploration initiative will require a more efficient approach to ascent flight design and operations. This paper presents a concept of continuous improvement in ascent flight design through an evolutionary process beginning with today's vehicles (Shuttle and expendable (ELV's)) and continuing into the next century with the Advanced Launch System (ALS) and Advanced Manned Launch System (AMLS). Figure 1 provides a pictorial view of the improvement path to be described in the following sections.

Improvements in launch probability, quality assurance, training techniques, and on-board autonomy will have to be made while simultaneously reducing operations costs and time lines. Attaining this considerably higher level of efficiency and speed will require an infusion of advanced technology in the form of automated flight design software tools, adaptive GN&C algorithms, advanced atmospheric sensors and improved on-board computational capabilities.

Section 2 describes the detailed objectives necessary to obtain efficiency improvements. Section 3 outlines the technology milestones along this evolutionary path and summarizes the accomplishments to date. Section 4 discusses the technology issues which must be addressed. Section 5 provides the candidate launch vehicle programs to be considered for this technology. Section 6 lists the key NASA contacts and Section 7 summarizes the paper.

2. OBJECTIVES

The objective of this concept is to significantly reduce the cost of ascent flight design while simultaneously reducing the required process time line and to significantly improve operations responsiveness and flexibility.

Today's ascent flight design process is characterized by extensive manpower and lead times of up to a year. Driving the lead time is the flight code re-configuration and mission control (and crew for Shuttle) training requirements. On-board G&C algorithms are generally non-adaptive for the atmospheric portion of flight, resulting in low probability of launch during seasons with dynamic upper atmosphere wind profiles. For Shuttle, multiple intact abort sites require extensive trajectory analysis to determine targeting values for the on-board computers. This combination of characteristics results in a process that requires significant engineering manpower to be applied many months prior to launch. If the launch date or other mission parameters change, many of these activities will have to be repeated.

To improve this process, changes must be made in a number of areas. Ascent flight design software tools need to be automated and re-hosted in state-of-the-art distributed computer systems. Launch probability can be increased by developing faster upper atmosphere wind measuring systems and modifying on-board G&C systems such that the vehicle can adapt to near launch time changes in the atmosphere. Mission control and crew training tools and techniques need to be standardized to relieve the analysis burden of the flight planners.

Finally automated flight design quality assurance approaches have to be developed that can certify launch readiness without requiring tremendous amounts of engineering manpower.

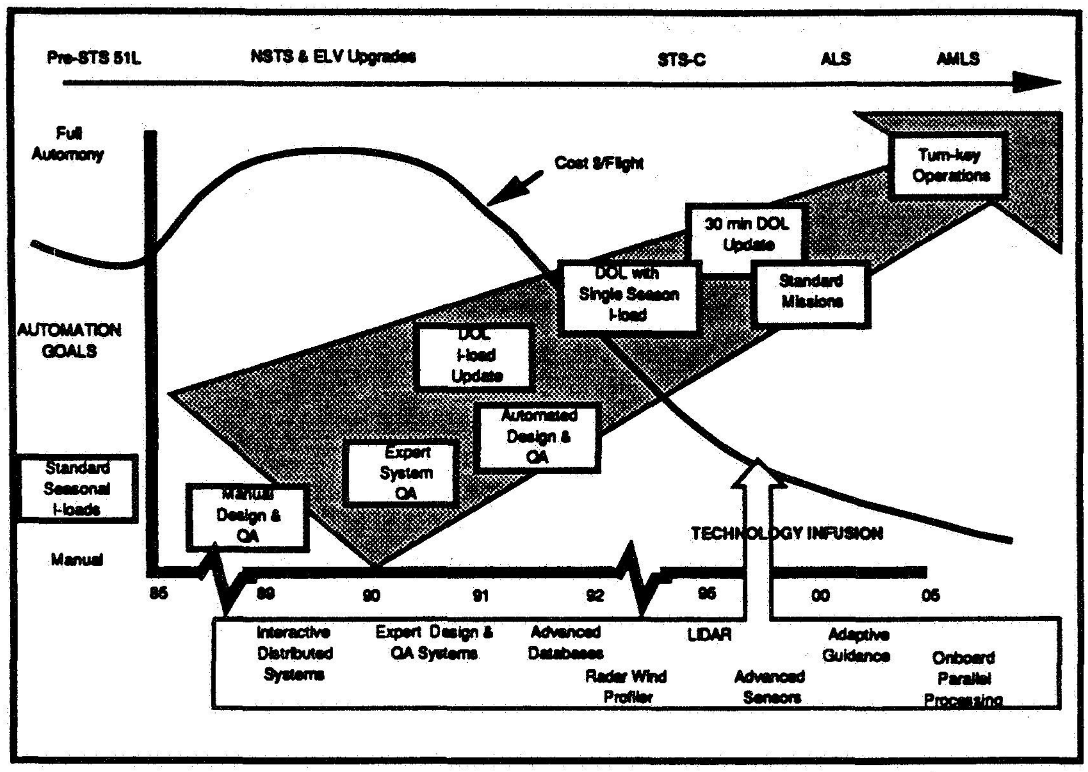

Figure 1 - Flight Design Improvement Path

3. TECHNOLOGY MILESTONES

The objectives described in the previous section can be organized into a number of technical milestones each incorporating specific capabilities. These milestones, taken together, constitute an evolutionary path. An overview of this path is provided in Figure 2. The following paragraphs describe the required technologies and suggested implementation strategies.

3.1 Automated Ascent Flight Design

For Shuttle, the task of designing the ascent trajectory has evolved from the engineering intensive approach used for the first missions to the current more streamlined approach, relying on standard seasonal trajectory designs. This approach has proved adequate for the launch rates experienced through the 1980's but can not cope with launch rates beyond 10 to 15 a year.

Software automation techniques coupled with state-of-the-art distributed computer systems need to be applied to this process if significant gains in efficiency are to be made.

This need is currently being addressed at JSC through several on-going activities. The Mission Operations Directorate is developing the Flight Analysis and Design System (FADS) to be the Shuttle flight design environment for the 1990's. This system will consist of a network of UNIX based

workstations using advanced software tools to perform all of the Shuttle flight design analysis tasks. The Mission Support Directorate is developing various new applications programs that will be more autonomous than the current versions and will be targeted for hosting on the FADS system when it becomes operational in 1993.

Beyond these steps, more advanced technology will be necessary to obtain total autonomy. Innovative applications of expert systems and advanced data base technology could be used in a system which would perform the majority of the flight design tasks.

3.2 Launch Probability Improvements

Currently, today's fleet of vehicles are constrained ,by aerodynamic loads, to launching in relatively benign upper atmosphere wind conditions. For Shuttle during the winter, these conditions can occur less than 50 percent of the time. Improvement in this situation can be obtained through development of near launch time trajectory update capability and by modifying the on-board GN&C system to be insensitive to changes in the atmospheric conditions.

The Shuttle program office is currently committed to implementing a day of launch (DOL) trajectory update system by the end of 1990. This approach uses the current Jimsphere wind measuring system to provide input data to a new software program. This program produces updated first stage guidance I-Loads tailored to the measured wind. It is projected that when using a wind profile measured 3 to 4 hours prior to launch, this system can improve launch probability from 10 to 20 percent, depending on the mission.

Further improvements in launch probability, other than structural changes to the vehicle, will require new wind measuring technology and/or new approaches to on-board first stage guidance and control.

The Shuttle program office in conjunction with MSFC is testing a doppler radar wind profiler as a replacement for the current Jimsphere system. Potentially this system could prove to be faster than the balloons while maintaining the same level of measurement accuracy. Measurement speed is important. The earlier prior to launch the measurement is taken ,the more margin for change in the wind is required. This additional margin to account for wind persistence degrades launch probability. Therefore, faster measurement means measurement closer to launch, which leads to lower wind persistence margin. The ultimate result is higher launch probability.

As part of the ALS program, another wind measurement system (LIDAR) using laser technology was being investigated. The emphasis of this activity was to develop an on-board wind measurement capability for adaptive G&C purposes. This is a technically ambitious objective, not guaranteed of success. However, this research could provide spin-off advances for ground based measuring systems in improved speed and accuracy.

The Mission Planning and Analysis Division of JSC is currently concentrating on improvements to on-board G&C algorithms that will provide more adaptability to atmospheric changes. These algorithms span the technical spectrum from simple modifications to the current G&C system, to completely closed loop algorithms requiring no pre-flight planning and maximum launch probability.

3.3 Standardized Mission Control and Crew Training

To date, control center and crew training have taken the approach of requiring the most accurate trajectory simulation possible. The rationale has been that to properly prepare the flight controllers and crew for any anomalous situations that might occur,they need the best representation of the nominal flight profile that exists. For Shuttle, this philosophy has greatly increased trajectory re-configuration costs.

The current Shuttle trajectory re-configuration process is driven to a start date many months prior to launch due to two requirements, on-board code preparation and mission control training. In Section 3.2 it was outlined how program changes are in work that will de-sensitize the vehicle from launch day atmospheric changes in order to improve launch probability. Inherent in these changes is the de-sensitizing of the on-board code from required updates induced by launch date changes. The net result of this new approach will

be more standardized flight code prepared one time prior to launch regardless of launch date. The requirement for an accurate training trajectory profile will become the driver for early flight design start dates.

Currently JSC is evolving toward a more standardized training scheme with the use of flight cycles vs. training cycles. A flight cycle is the trajectory design that will be used on the actual mission while the training cycle is only for integrated control center simulations. The difference in the two is the absence of the rigorous flight readiness verification for the training cycle. The activities associated with the flight design are identical and still need to be performed at least twice per mission.

This is a significant improvement in operations cost but has not realized all the gains that are possible. For further improvement, it will be necessary to re-examine the training requirement of best possible simulation trajectory at any cost.

In reality, the flight controllers and crew have been operating under a mis-conception. The Shuttle trajectory changes radically in the presence of different upper atmosphere winds. Since it is impossible to predict wind profiles more than a few hours in advance, all training is performed with statistical mean monthly wind profiles. The probability that the wind used for training would match the actual launch wind is extremely small. Therefore the flight controllers and crew are not training to the actual flight profile, within some tolerance, no matter how accurate a flight design is being used.

An approach using standard trajectory designs for training could be developed. Trajectory sets could be defined one time based on gross mission requirements such as orbit altitude, orbit inclination, abort selection philosophy, etc.. This approach would present just as accurate a picture of how the trajectory will look as today's technique, but at a significantly reduced cost in flight design.

3.4 Automated Quality Assurance Systems

Flight design quality assurance is the process that insures the designed trajectory meets all subsystem constraints, is compatible with the onboard flight software, and satisfies all mission objectives. For today's fleet of launch vehicles, this process relies on intensive engineering analysis. If cost reductions are to be realized in this area without decreases in product quality, automation has to occur.

In general, any quality assurance process can be defined by a set of pass/fail criteria. Conceptually, a system could be produced that uses flight design trajectory data as input to an automated expert system. This system would apply well defined pass/fail criteria against this trajectory data and alert the expert flight designer of any rule violations. Although not removed from the process, the workload of the expert engineer responsible for quality assurance would be significantly reduced.

At JSC, the Mission Support and Mission Operations directorates are developing such a system for ascent Shuttle flight design. One of the outcomes of the rush to make the Shuttle operational was the lack of flight design process documentation. Since 1986 these two organizations have been creating a flight design quality assurance rule base which will be completed for the ascent and insertion flight phases during 1990. The next planned steps are to develop automated software applications of these rules for incorporation in the FADS distributed computer system. To date, this activity has been some what narrow focused to the areas of expertise of the two directorates. If maximum reductions in quality assurance costs are to be realized, this activity needs to become program wide and supported by the Shuttle program office and the integration contractor.

An area that quality assurance automation is being supported by the Shuttle program office is in the development of the day of launch trajectory update system described in Section 3.2. This system will be able to update the set of guidance I-Loads that define the first stage trajectory within a few hours of launch. This I-Load set is flight critical and a method had to be developed such that flight safety could still be assured if these I-Loads were changed. What has been adopted and is currently in development is an automated pass/fail rule base formulated by the expert G&C engineers currently responsible for flight readiness assessments. This automated process will be operational when this trajectory update capability comes on line in late 1990.

MAJOR MILESTONES (1990-2005)

Technology Availability:	Products:	
• Interactive / Distributed Systems		Today
• Flight Design Expert Systems		
	• Day of Launch I-load Update	1990
• Advanced DB's for Flight Design		1991
	• Expert System I-load Verif.	
	• Auto I-load Design	1992
• Radar Wind Profiler	• FADS	1993
	• FSW for single season I-load	
• Adaptive Guidance Algorithms		1995
• LIDAR Technology		1997
• Advanced Sensors	• 30 min DOL I-load Design	1998
• Flight Qualified Parallel Proc.		2000
	• Onboard Autonomy	2005

Figure 2 - Technology Milestones

4. TECHNOLOGY ISSUES

In order to reach the objectives defined in Section 2, two major technology issues need to be resolved; significantly faster measurement of upper atmosphere winds without reducing accuracy and significantly higher levels of on-board computation capability. It is felt that technology improvements in these areas combined with state-of-the-art technology in computer systems for analysis, state-of-the-art software approaches and a commitment of resources to the effort will bring about the changes necessary to reach really low levels of operations cost per flight.

As discussed in section 3.2, a fast, accurate upper atmosphere wind measuring system would increase launch probability by reducing the margin required to protect for changes in the wind. If a system could be produced that would support measurement less than 30 minutes prior to launch, launch probability degradation due to wind persistence would nearly be eliminated. The demonstration activities by NASA on radar wind profilers and the ALS program on LIDAR should be actively supported as the right steps toward this goal.

All of today's launch vehicles use on-board computers developed prior to the early 1970's. The tremendous increases in computational speed and storage capacity occurring in the late 1970's and 80's need to be exploited for the next generation of vehicles. Technologies such as parallel processing have produced commercial machines with thousands of times the speed and storage capability of the Shuttle GPC's at a fraction of the size, weight and power requirements. This type of technology should be actively applied to on-board flight and space rated systems. The level of computation capability currently available commercially if applied on-board would allow near complete autonomy and elimination of major portions of the real time flight support necessary today.

5. CANDIDATE PROGRAMS

Generally the topics addressed in this paper could be applied to any launch vehicle in today's fleet or that might be developed in the future. However, retro-fitting some of these concepts into a mature

design may be more costly than any benefit that would come from the change.

For the Shuttle and possibly the existing ELV's, implementing the concepts associated with flight design and quality assurance automation, launch probability improvement, and training standardization seem to make cost sense. Full on-board autonomy and advanced on-board computers probably should wait for the ALS and AMLS programs.

Shuttle-C, as a direct spin-off from Shuttle technology, would fall in the same category as the Shuttle and ELV's.

6. KEY NASA CONTACTS

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7. SUMMARY

This paper has outlined some concepts that would provide cost benefits to operations of existing launch vehicles such as the Shuttle and ELV's and new start programs such as ALS and AMLS. The technical objectives of improvements in launch probability, quality assurance, training techniques, and on-board autonomy while simultaneously reducing flight design costs will require a combination of state-of-the-art and advanced technologies.

To realize these potential gains in cost effectiveness and responsiveness to national launch rate demands, it will require a high level of commitment to developing the advanced technologies previously described in addition to support of the current ongoing activities by the Mission Operations and Support Directorates.

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PRESENTATION 3.1.2

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ADVANCED TRAINING SYSTEMS

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM

WILLIAMSBURG, VIRGINIA
NOVEMBER 7-9, 1989

ADVANCED TRAINING SYSTEMS

WHITE PAPER

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Space Transportation Avionics Technology Symposium
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I. INTRODUCTION

A. General Introduction

Training is a major endeavor in all modern societies: new personnel must be trained to perform the task(s) which they were hired to perform, continuing personnel must be trained to upgrade or update their ability to perform assigned tasks, and continuing personnel must be trained to tackle new tasks. Common methods include training manuals, formal classes, procedural computer programs, simulations, and on-the-job training. The latter method is particularly effective in complex tasks where a great deal of independence is granted to the task performer. Of course, this training method is also the most expensive and may be impractical when there are many trainees and few experienced personnel to conduct on-the-job training.

NASA's training approach has focussed primarily on on-the-job training in a simulation environment for both crew and ground-based personnel. This process worked relatively well for both the Apollo and Space Shuttle programs. Space Station Freedom and other long range space exploration programs coupled with limited resources dictate that NASA explore new approaches to training for the 1990's and beyond.

This report describes specific autonomous training systems based on artificial intelligence technology for use by NASA astronauts, flight controllers, and ground-based support personnel that demonstrate an an alternative to current training systems. In addition to these specific systems, the evolution of a general architecture for autonomous intelligent training systems that integrates many of the features of "traditional" training programs with artificial intelligence techniques is presented. These Intelligent Computer-Aided Training (ICAT) systems would provide, for the trainee, much of the same experience that could be gained from the best on-the-job training. By integrating domain expertise with a knowledge of appropriate training methods, an ICAT session should duplicate, as closely as possible, the trainee undergoing on-the-job training in the task environment, benefiting from the full attention of a task expert who is also an expert trainer. Thus, the philosophy of the ICAT system is to emulate

the behavior of an experienced individual devoting his full time and attention to the training of a novice--proposing challenging training scenarios, monitoring and evaluating the actions of the trainee, providing meaningful comments in response to trainee errors, responding to trainee requests for information, giving hints (if appropriate), and remembering the strengths and weaknesses displayed by the trainee so that appropriate future exercises can be designed.

B. BACKGROUND

Since the 1970's a number of academic and industrial researchers have explored the application of artificial intelligence concepts to the task of teaching a variety of subjects [Sleeman and Brown, 1982; Yazdani, 1986; Wenger, 1987] (*e.g.*, computer programming in Lisp [Anderson, 1985; Anderson, Boyle and Reiser, 1985] and Pascal [Johnson and Soloway, 1985], economics [Shute and Bonar, 1986], geography [Carbonell, 1970], and geometry [Anderson, Boyle and Yost, 1985]). The earliest published reports which suggested the applications of artificial intelligence concepts to teaching tasks appeared in the early 1970's [Carbonell, 1970; Hartley and Sleeman, 1973]. Hartley and Sleeman [Hartley and Sleeman, 1973] actually proposed an architecture for an intelligent tutoring system. However, it is interesting to note that, in the sixteen years which have passed since the appearance of the Hartley and Sleeman proposal, no agreement has been reached among researchers on a general architecture for intelligent tutoring systems [Yazdani, 1986].

Along with the extensive work on intelligent tutoring systems for academic settings has come the development of systems directed at training. Among these are Recovery Boiler Tutor [Woolf, Blegen, Jansen, and Verloop, 1986], SOPHIE [Brown, Burton and de Kleer, 1982], and STEAMER [Hollan, Hutchins and Weitzman, 1984]. These differ from the tutoring systems mentioned above in providing a simulation model with which the student or trainee interacts. Although these intelligent training systems each use the interactive simulation approach, they each have very different internal architectures. Further, there appears to be no agreement, at present, on a general architecture for such simulation training systems. The work reported here builds on these previous efforts and our own work [Loftin, Wang, Baffes and Rua, 1987; Loftin, Wang, Baffes, and Hua, 1988; Loftin, Wang, Baffes, and Hua, 1989a and b] to develop specific intelligent training systems as well as a general approach to the design of intelligent training systems which will permit the production of such systems for a variety of tasks and task environments with significantly less effort that is now required to "craft" such a system for each application.

C. TRAINING VERSUS TUTORING

The ICAT systems and architecture described here have been developed with a clear understanding that training is not the same

as teaching or tutoring [Harmon, 1987]. An industrial or governmental training environment differs in many ways from an academic teaching environment These differences are important in the design of an architecture for an intelligent training system:

- Assigned tasks are often mission-critical, placing the responsibility for lives and property in the hands of those who have been trained.

- Personnel may already have significant academic and practical experience to bring to bear on their assigned task.

- Trainees make use of a wide variety of training techniques, ranging from the study of comprehensive training manuals to simulations to actual on-the-job training under the supervision of more experienced personnel.

- Many of the tasks offer considerable freedom in the exact manner in which they may be accomplished.

Those undergoing training for complex tasks are usually well aware of the importance of their job and the probable consequences of failure. While students are often motivated by the fear of receiving a low grade, trainees know that human lives and/or expensive equipment may depend on their skill in performing assigned tasks. This means that trainees may be highly motivated, but it also imposes on the trainer the responsibility for the accuracy of the training content (*i.e.*, verification of the domain expertise encoded in the system) and the ability of the trainer to correctly evaluate trainee actions. The ICAT approach is intended, not to impart basic knowledge, but to aid the trainee in developing skills for which he already has the basic or "theoretical" knowledge. In short, this training system architecture is designed to help a trainee put into practice that which he already intellectually understands. The system must take into account the type of training that both precedes and follows, building on the knowledge gained from training manuals and rule books while preparing the trainee for and complementing the on-the-job training which may follow. Perhaps most critical of all, trainees must be allowed to carry out an assigned task by any valid means. Such flexibility is essential so that trainees are able to retain, and even hone, an independence of thought and develop confidence in their ability to respond to problems, even problems which they have never encountered and which their trainers never anticipated.

IV. APPLICATIONS

The ICAT architecture was originally applied to a training system for NASA flight controllers learning to deploy satellites from the Space Shuttle. The same architecture has been used in the construction of ICAT systems for training astronauts for SpaceLab missions and engineers who test the Space Shuttle main

propulsion system. Although these tasks are quite different and are performed in very dissimilar environments, the same system architecture has proven to be adaptable to each. Below is a brief summary of the specific systems that have been built or are currently under development:

A. PD/ICAT: [Payload-assist module Deploys/ICAT System]

A comprehensive intelligent computer-aided training system for use by Flight Dynamics Officers in learning to deploy PAM (Payload-Assist Module) satellites from the Space Shuttle. PD/ICAT contains four expert systems that cooperate via a blackboard architecture.

B. VVL/ICAT: [Vacuum Vent Line/ICAT System]

A PC-based intelligent computer-aided training system for use by mission and payload specialists in learning to perform fault detection, isolation, and reconfiguration on the Spacelab VVL system. VVL/ICAT consists of an integrated expert system and graphical user interface.

C. MPP/ICAT: [Main Propulsion Pneumatics/ICAT System]

A comprehensive intelligent computer-aided training system for use by test engineers at NASA/Kennedy Space Center in learning to perform testing of the Space Shuttle Main Propulsion Pneumatics system. MPP/ICAT is currently under development and makes use of the same architecture as PD/ICAT.

D. IPS/ICAT: [Instrument Pointing System/ICAT System]

A comprehensive intelligent computer-aided training system for use by payload and mission specialists at NASA/Johnson Space Center and Marshall Space Flight Center in learning to utilize the IPS on Spacelab missions. IPS/ICAT is currently under development and makes use of the same architecture as PD/ICAT.

III. A GENERAL ARCHITECTURE FOR INTELLIGENT TRAINING SYSTEMS

The projects described in the previous section have served as vehicles to aid in the design and refinement of an architecture for intelligent training systems that has significant domain-independent elements and is generally applicable to training in procedural tasks common to the NASA environment. The ICAT system architecture is modular and consists of five basic components:

- A user interface that permits the trainee to access the same information available to him in the the task environment and serves as a means for the trainee to take actions and communicate with the intelligent training system.

- A domain expert which can carry out the task using the same information that is available to the trainee and which also contains a list of "mal-rules" (explicitly identified errors that novice trainees commonly make).

- A training session manager which examines the actions taken by the domain expert (of both correct and incorrect actions in a particular context) and by the trainee and takes appropriate action(s). [Loftin, Baffes and Wang, 1988]

- A trainee model which contains a history of the individual trainee's interactions with the system together with summary evaluative data.

- A training scenario generator that designs increasingly-complex training exercises based on the knowledge of the domain expert, the current skill level contained in the trainee's model, and any weaknesses or deficiencies that the trainee has exhibited in previous interactions. [Loftin, Wang, and Baffes, 1988; Loftin, Wang, and Baffes, 1989]

Figure 1 contains a schematic diagram of the ICAT system. Note that provision is made for the user to interact with the system in two distinct ways and that a supervisor may also query the system for evaluative data on each trainee. The blackboard serves as a common repository of facts for all five system components. With the exception of the trainee model, each component makes assertions to the blackboard, and the expert system components look to the blackboard for facts against which their rules pattern match. A comprehensive effort has been made to clearly segregate domain-dependent from domain-independent components.

IV. SYSTEM INTEGRATION

The ICAT architecture described above was originally implemented in a Symbolics 3600 Lisp environment using Inference Corporation's ART for the rule-based components. The architecture is currently available for unix workstations. The user interface is implemented in X-Windows, the rule-based components in CLIPS [CLIPS is the acronym for a NASA-developed expert system shell written in C], and supporting code in C.

V. TRAINING PERFORMANCE

The original system developed with this architecture (PD/ICAT) has been used by both expert and novice flight controllers at NASA/Johnson Space Center. An extensive investigation of the performance of novices using the system has been conducted. Figure 2 shows two measures of performance: (1) the time required to perform the nominal task as a function of the number of training experiences and (2) the number of errors made during the performance of the nominal task as a function of the number of training experiences. It is interesting to note that,

although the novices used in this investigation had very different levels of prior experience related to the task, all novices rapidly approached the same level of proficiency.

VI. CONCLUSIONS

A general architecture for ICAT systems has been developed and applied to the construction of three ICAT systems for very different tasks. Use by novices of an ICAT application built upon this architecture has shown impressive trainee performance improvements. With further refinement and extension, this architecture promises to provide a common foundation upon which to build intelligent training systems for many tasks of interest to the government, military, and industry. The availability of a robust architecture that contains many domain-independent components serves to greatly reduce the time and cost of developing new ICAT applications.

REFERENCES

[Anderson and Reiser,1985] Anderson, J.R. and Reiser, B.J., The LISP Tutor, *Byte,* Vol. 10, No. 4, pp. 159-175, April, 1985.

[Anderson, Boyle and Reiser, 1985] Anderson, J.R., Boyle, C.F., and Reiser, B.J., Intelligent Tutoring Systems, *Science,* Vol.225, No. 4698, pp. 456-462, 1985.

[Anderson, Boyle and Yost, 1985] Anderson,J.R., Boyle C. F., and Yost, G., The Geometry Tutor, *Proceedings of the Ninth International Joint Conference on Artificial Intelligence*, Los Angeles, CA, 1985, pp. 1-7.

[Brown, Burton and de Kleer, 1982] Brown, J.S., Burton, R.R., and de Kleer, J., Pedagogical, Natural Language and Knowledge Engineering Techniques in SOPHIE I, II, and III, in Sleeman, D. and Brown, J.S., (eds.), *Intelligent Tutoring Systems*, Academic Press,London, 1982, p. 227.

[Carbonell,1970] Carbonell, J.R. AI in CAI: An Artificial Intelligence Approach to CAI, *IEEE Transactions on Man-Machine Systems*, Vol. 11, No. 4, pp. 190-202, 1970.

[Harmon, 1987] Harmon, P. Intelligent Job Aids: How AI Will Change Training in the Next Five Years, in Kearsley, G., ed., *Artificial Intelligence and Instruction: Applications and Methods,* Addison Wesley Publishing Co., Reading, MA, 1987.

[Hartley and Sleeman, 1973] Hartley, J.R. and Sleeman, D.H., Towards Intelligent Teaching Systems, *International Journal of Man-Machine Studies*, Vol. 5, pp. 215-236, 1973.

[Hollan, Hutchins and Weitzman, 1984] Hollan, H.D., Hutchins, E.L., and Weitzman, L. Steamer: An Interactive Inspectable

Simulation-based Training System, *AI Magazine*, Summer, 1984, pp. 15-27.

[Johnson and Soloway, 1985] Johnson, W.L. and Soloway, E. PROUST, *Byte*, Vol. 10, No. 4, pp. 179-190, April, 1985.

[Kearsley, 1987] G. Kearsley, ed., *Artificial Intelligence and Instruction*, Addison-Wesley, Reading. MA, 1987.

[Loftin, Wang, Baffes and Rua, 1987] Loftin, R.B., Wang, L., Baffes, P., and Rua, M., An Intelligent Computer-Aided Training System for Payload-Assist Module Deploys, *Proceedings of the First Annual Workshop on Space Operations, Automation & Robotics* (SOAR '87), NASA/Johnson Space Center, Houston, TX, August 4-6, 1987.

[Loftin, Baffes and Wang, 1988] Loftin, R.B., Baffes, P., and Wang, L, An Approach to the Diagnosis of Trainee Errors in an Intelligent Training System, unpublished report.

[Loftin, Wang, Baffes, and Hua, 1988] Loftin, R.B., Wang, L., Baffes, P., and Hua, G., "An Intelligent Training System for Space Shuttle Flight Controllers," *Informatics and Telematics 5* (3), 151 (1988).

[Loftin, Wang, and Baffes, 1988] Loftin, R.B., Wang, L., and Baffes, P., "Simulation Scenario Generation for Intelligent Training Systems," *Proceedings of the Third Artificial Intelligence and Simulation Workshop*, August 22, 1988, St. Paul, MN, pp. 69-74.

[Loftin, Wang, Baffes, and Hua, 1989a] Loftin, R.B., Wang, L., Baffes, P., and Hua, G., "An Intelligent System for Training Space Shuttle Flight Controllers in Satellite Deployment Procedures," to be published in *Machine Mediated Learning*.

[Loftin, Wang, Baffes, and Hua, 1989b] Loftin, R.B., Wang, L., Baffes, P., and Hua, G., "An Intelligent Training System for Space Shuttle Flight Controllers" in *Innovative Applications of Artificial Intelligence*, edited by H. Schorr and A. Rappaport (Menlo Park, CA: AAAI Press, 1989), pp. 15-24.

[Loftin, Wang, and Baffes, 1989] Loftin, R.B., Wang, L., and Baffes,P., "Intelligent Scenario Generation for Simulation-Based Training," *Proceedings of the American Institute for Aeronautics and Astronautics Computers in Aerospace VII Conference*, Monterey, CA, October 3-5, 1989, pp. 581-588.

[Shute and Bonar, 1986] Shute, V. and Bonar, J.G., An Intelligent Tutoring System for Scientific Inquiry Skills, *Proceedings of the Eighth Cognitive Science Society Conference* Amherst, MA, 1986, pp. 353-370.

[Sleeman and Brown, 1982] D. Sleeman and J.S. Brown, eds., *Intelligent Tutoring Systems*, Academic Press, London, 1982.

[Sleeman, 1982] Sleeman, D.H. Inferring (mal) rules from pupils' protocols. *Proceedings of the European Conference on Artificial Intelligence*, Orsay, France, 1982, pp. 160-164.

[Wenger, 1987] Wenger, E., *Artificial Intelligence and Tutoring Systems*, Morgan Kaufmann Publishers, Los Altos, CA, 1987.

[Woolf, Blegen, Jansen and Verloop, 1986] Woolf B.P., Blegen, D., Jansen, J.H., and Verloop, A., Teaching a Complex Industrial Process, *Proceedings of the National Conference on Artificial Intelligence*, Vol. II, Austin, TX, 1986, pp. 722-728.

[Yazdani, 1986] Yazdani, M. "Intelligent Tutoring Systems Survey," *Artificial Intelligence Review*, Vol. 1, p. 43, 1986.

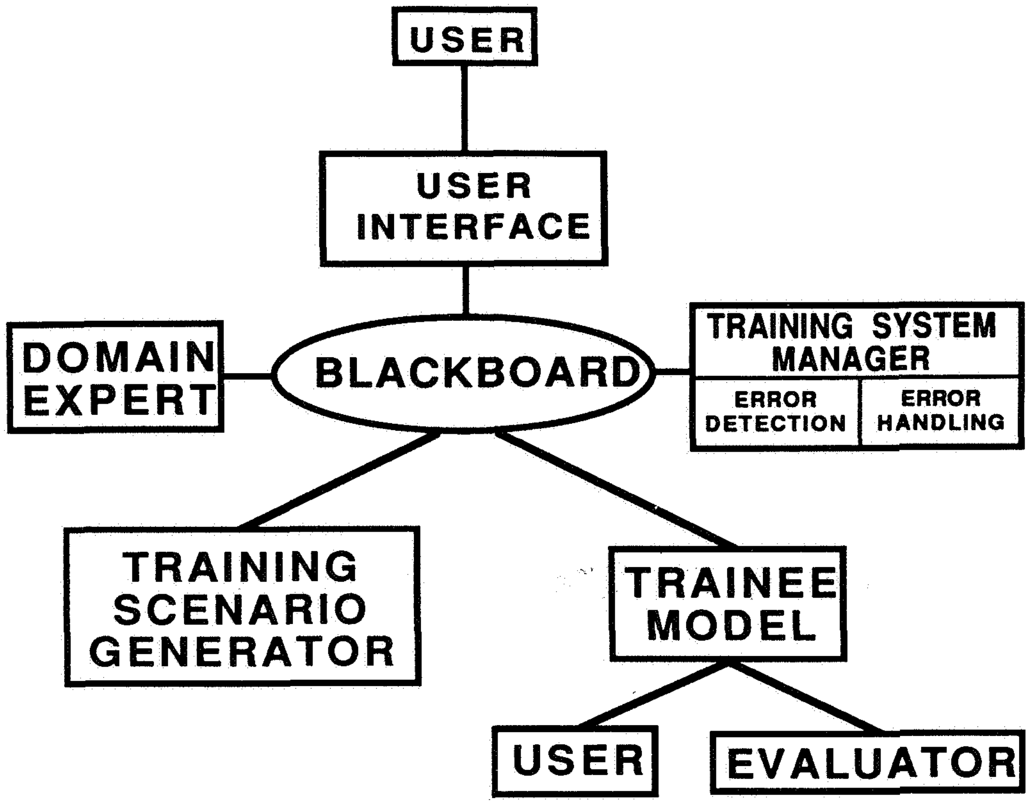

Figure 1. A Schematic Diagram of the General Architecture

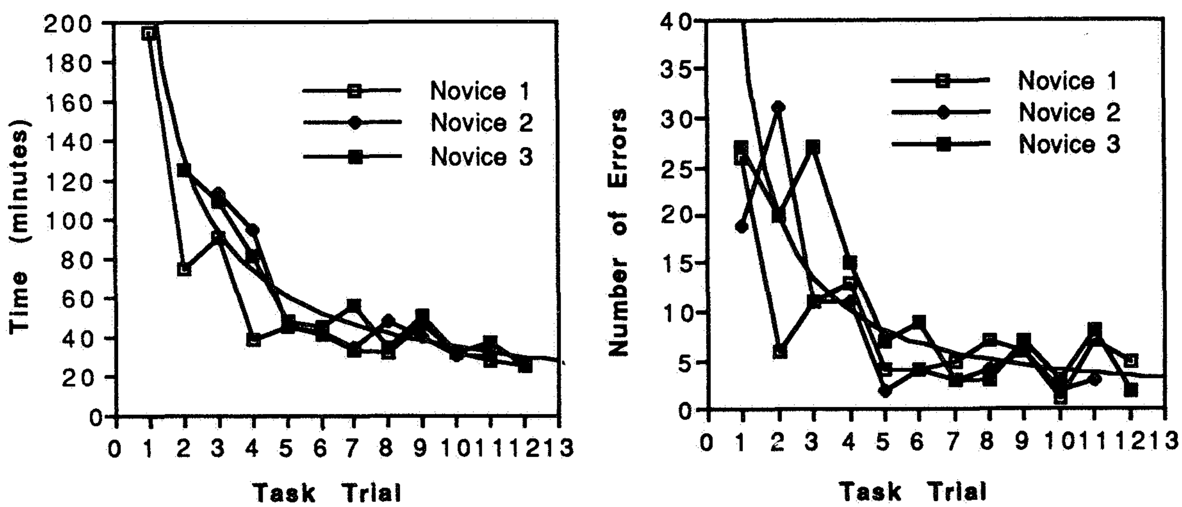

Figure 2. Performance of Novices Using the PD/ICAT System

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PRESENTATION 3.1.3

N91-17035

AUTONOMOUS SPACECRAFT CONTROL

WHITE PAPER ON

ADVANCED AVIONICS CONCEPTS : AUTONOMOUS SPACECRAFT CONTROL

NASA Johnson Space Center

Engineering Directorate
Systems Development and Simulation Division
Tracking and Communication Division
Avionics Systems Division

Mission Support Directorate
Mission Planning and Analysis Division

December 1989

1. INTRODUCTION

A significant increase in space operations activities is expected because of Space Station Freedom (SSF) and long range Lunar base missions and Mars exploration. There could be several precursor missions to support planning and operations in Lunar and Mars orbits. These precursor missions will involve placing necessary communications satellites in orbit around Mars or the Moon and other support systems on the surface for long range manned operations. Many of the systems will undergo initial testing in the Earth orbital environment.

Space operations will also increase as a result of space commercialization (especially the increase in satellite networks). It is anticipated that the level of satellite servicing operations will grow tenfold from the current level within the next 20 years. This growth can be sustained only if the cost effectiveness of space operations is improved. Cost effectiveness in this perspective translates into operational efficiency with proper effectiveness. This paper presents a concept of advanced avionics, autonomous spacecraft control, that will enable the desired growth, as well as maintain the cost effectiveness (operational efficiency) in satellite servicing operations.

Section 2 describes the concept of advanced avionics that allows autonomous spacecraft control with a brief description of each component. Section 3 describes some of the benefits of autonomous operations. Section 4 provides a technology utilization breakdown in terms of applications. Section 5 provides the candidate programs that will benefit from various autonomous control technologies and their development. Section 6 provides the current status of activities and future milestones expected in each area of autonomous spacecraft control. Section 7 discusses the technology needs and current program holes in the autonomy development. The summary is provided in section 8.

2. ADVANCED AVIONICS CONCEPTS

The advanced avionics concept is based on **total** autonomous control of a spacecraft in all applicable flight regimes without any help from external elements. There are two parts to this basic requirement: first, the onboard avionics system must be capable of performing all functions (This is a necessary driving factor), and second, it must perform all functions without any help from external elements (This is a sufficient part.) The first part identifies necessary functions along with required subsystems and components, while the second part increases its reliability, safety and mission readiness.

By advanced avionics we mean a highly integrated system capable of performing autonomous spacecraft control with high reliability and safety. In this perspective, the system is designed to achieve mission goals (without being dependent on other systems) and to accomplish those functions for which external help is unavailable. By design, the system has proper fault diagnosis, isolation, and recovery capability and is able to cope with unanticipated changes in the surrounding environment. With such capabilities, the system performance results

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in high operational efficiency, thus reducing the cost of spacecraft operations.

There are four mission flight segments (see figure 1) considered here for applying our concept: 1) ascent, 2) rendezvous, 3) proximity operations, and 4) landing. Some experts consider parking orbit maintenance and interplanetary cruise as other flight segments. However, the activities performed by a spacecraft during these flight regimes is a subset of activities performed during the coasting phase of the rendezvous segment. Thus, the autonomy requirements are derived indirectly, and a spacecraft capable of autonomous rendezvous is also capable of parking orbit maintenance.

A basic requirement, autonomous control, was applied to each of these segments, and a conceptual design of the avionics system was developed. Each flight segment has some unique control requirements. However, the conceptual design accommodated all these well without having a major impact on the overall architecture. The conceptual design of the avionics system has four major components as shown in figure 2. Each component can be further tailored according to specific flight segment requirements and several sub-components can be added for completeness. Each component is briefly described in following paragraphs.

The flight computer is a key component of an overall autonomous spacecraft control system that includes advanced sensors and intelligent controllers. Advanced computer architectures are required to handle very high computational loads, to interface with distributed, multiple sensor systems, and to properly control the effector systems. The architecture must be capable of performing fault detection, isolation and necessary reconfiguration of the internal hardware. The flight computer component may be a network of many separate processors rather than a single processor. Special processors may be needed for specific functions such as machine vision.

The flight software component must be capable of dynamic adjustment according to the flight segment. This component is responsible for planning the mission, detecting hazards and faults during the mission, evaluating their effects and generating proper responses, and controlling the trajectory and the mission timeline. Typical navigation, guidance and control software modules are integrated parts of this component. The architecture of this component must be compatible with the distributed nature of the computer hardware and robust for upscaling at the higher function level. Such a system is expected to do the original mission planning onboard the spacecraft and thus will be considerably more capable than current onboard systems.

The advanced sensors component is related to new technology development that is targeted to autonomously measure relevant parameters with high accuracy in real time. These include onboard tracking systems to provide relative state measurements to the spacecraft navigation systems. Operations such as rendezvous, stationkeeping, proximity operations, docking, traffic management, and collision avoidance require measurements of position, attitude, and rates relative to a point or feature on a target spacecraft or object. Operations such as spacecraft landing require measurements of position and rates relative to a landing site, and possibly measurements of terrain contour to avoid hazards such as holes, rocks, and steep slopes. The operation of the sensors must be very reliable with long life and low failure rates. Furthermore, sensors must have built-in health monitoring that provides desired inputs to the flight software component. An advanced sensor may use a data fusion concept to derive a meaningful parameter by appropriately combining several measured parameters. The fusion concept can be applied to data from several sensors to evolve an integrated but distributed sensor system. Alternatively, new technologies may enable weight and power savings with a single sensor replacing multiple sensors.

The intelligent effector is the fourth component of our conceptual design. There will be interfaces with the flight software via the flight computer component. Intelligent effectors are envisioned to have fault tolerant designs and built-in performance monitors.

3. EFFICIENCY VIA AUTONOMOUS OPERATIONS

The autonomous spacecraft control achieved through this type of avionics system will result in several benefits for overall mission operations. The autonomy onboard the spacecraft will increase the effectiveness with which the spacecraft can perform orbital operations, as well as simplify the current operational procedures requiring periodic mission updates and constant communication with the ground. A major part of calculating the communication windows and associated timelines will be reduced along with the associated support systems. Because the system has built-in support elements, there will less interaction with ground support systems. As a result, the ground facilities will be able to handle more spacecraft operations. These factors will reduce the overall cost of the operations. Thus, there will be a significant increase in the operational efficiency, which translates into cost effectiveness or the reduced unit cost of spacecraft operations.

The reliability and mission readiness of a spacecraft will be improved significantly, especially for the mission planning process that is needed for time-limited missions. It will reduce the planning/replanning workload for the crew as well as for the ground operations.

Success probability of a mission is enhanced simply because the onboard systems are capable of surviving failures by adapting to new configurations. Furthermore, the system is capable of handling the unanticipated changes in the operating environment and adjusting its mission plan accordingly.

Some missions can not be performed without some form of autonomy. For example, an unmanned mission to Mars, which involves events such as pinpoint landing, ascent and rendezvous, could not be accomplished without autonomy.

Since the system architecture is adaptable to various flight segments, there is a capability to switch and/or change the components and subsystems as applicable. The system will require strict enforcement of interface standards and thus improve commonality and modularity among the hardware and software components. The manufacturing, integration and launch processing activities will be standardized, resulting in reduced cost of operations.

As a side benefit, the initial implementation of the autonomous system will provide a basis for estimating the incremental cost and the benefit of greater autonomous capability. Currently, there is no basis for estimating these cost factors.

4. TECHNOLOGY UTILIZATION

Infusion of newer and emerging technologies into a spacecraft system is subject to much closer scrutiny today than in earlier times. The right investments made at the right time will be the critical factor in the efficiency, reliability, and flexibility of spacecraft control functions in the future. Justifying this technology is not a simple task. Infusion of technology produces tangible and intangible results. A seemingly intangible result in one area of the spacecraft system can produce a tangible effect in another area. To assess accrued benefits, since the impacts vary at various levels, all levels of the spacecraft system must be evaluated.

4.1 CLASSIFICATION OF TECHNOLOGY UTILIZATION

For purposes of engineering (i.e., performance) evaluation and cost justification, three kinds of technology utilization can be identified:

1) Replacement applications are those which are needed to replace obsolete hardware or perform existing functions more efficiently, effectively or cheaply. Development work performed at a subsystem level or component level will result in this type of applications. For example:

- -Laser Ring Gyro Sensor (improved performance)
- -Upgraded Flight Computer with higher speed (to replace the current computers which are no longer manufactured and are becoming obsolete)
- -Global Positioning System replacement of Tactical Air Navigation System (replacement of old system as well as improvement in performance)

-New algorithm to compute orbit transfer delta-V's that takes care of finite burn effects and reduces number of maneuvers during rendezvous profile

2) Enhancing(Complementary) applications not only help to improve the process but offer advantage for additional support functions and capabilities as well. Research work involving new technology at a system or subsystem level usually results in this type of applications. For example:

-Laser Docking Sensor that provides range and range rate measurements as well as relative attitude measurements required for docking
-Vision sensors and associated algorithms that process the data at pixel level and generate orientation information in the reference coordinate frame
-Variable Thrust Engines will provide thrusting capability for a wide range of delta-V's and also handle G-sensitive payloads at the same time

3) Enabling(Essential) applications are those which are essential and absolutely required for future missions. Without these research applications, the mission can not succeed e.g., autonomy for Mars operations. An Earth based control center can not actively participate in the mission operations with the required time granularity. As a result of examining functionality from the perspective of new technology, the emphasis for enabling applications is on deriving unique design approaches and operational effectiveness. For example:

-Laser Docking Sensor for unmanned spacecraft docking
-Distributed computing and parallel processing
-Role of artificial intelligence technology in automated FDIR and replanning
-Cooperating expert systems
-Position Reference or tracking systems that provide necessary measurements for robotic path planning
-Algorithms based on new theoretical frameworks (e.g., fuzzy logic theory) that handle imprecise measurements or information
-Computer vision system for detecting safe planetary landing areas in real time

These three types of applications are also complemented by another dimension which must be considered when analyzing infusion of technology into existing processes. This dimension is the operations level. Technology applications integrated with other existing subsystems in operations provide a major benefit, especially when systems synergism between components can be created.

5. CANDIDATE PROGRAMS

A large part of the cost of introducing new technology and systems is determined by up-front hardware and software expenses, and maintenance expenses incurred during the lifetime of the application. Commonality can reduce program costs significantly, by spreading non-recurring costs across multiple programs, and by economies of scale. Compared to benefits, the cost items are more readily identified. Yet, the task of estimating those costs has never been perfected. The problem becomes even more complex on the benefit side. There are two sides to the problem: the benefits must be 1) identified, and 2) quantified.

Replacement applications, as described in previous section have the most impact at the component and subsystem levels and are most readily analyzed. Savings potentials can be determined and reliability improvements can be identified.

Enhancing applications improve the quality of performance as well as the reliability, just as the replacement applications. These applications will make the mission operations process more efficient by providing new and better capabilities.

Enabling applications involve an assessment of alternatives which currently do not exist and the associated risks. Concerns and issues with these types of technology infusions reside at the major system level. Certain missions cannot be successfully completed without these types of technology, for example, the Mars Rover Sample Return mission (MRSR).

While a given program may utilize technologies from more than one of the above classifications, it is useful to group existing and contemplated programs into one of the three areas. From a managerial and programmatic perspective, this effort serves to identify a program with the primary technological level driving (or anticipated to be driving) its success. As distinct from a technical analysis and tradeoff perspective, this programmatic viewpoint serves as a guideline to pervade all aspects of a project.

Table I illustrates a possible grouping of selected NASA programs. Several programs are listed under more than one group. The variety among individual programs within a given classification serves to illuminate the point that technology utilization transcends more generally accepted groupings of programs such as manned vs. unmanned or Earth environment vs. planetary. This indicates a need for sensitivity to intra- and inter-organizational arrangements and working relationships.

Table II identifies functions need by various flight programs, so that the programmatic priorities can be attached and inter-organizational arrangements can be assured. For example, applications developed for autonomous proximity and docking operations can be utilized in several programs. Such applications will therefore have the largest pay-off for its investment. In this table, there are two entries in several columns signifying that the applications are in overlapping categories; in the autonomous rendezvous area, the National Space Transportation System (NSTS) program has some replacement and some enhancement type applications.

6. CURRENT RESEARCH WORK AND PLANS

Advanced development of technologies and systems serves to reduce program development risk and provide better performance. Ongoing research work is focused on the needs identified in the previous sections with emphasis on the operations efficiency achieved through autonomy. Research work is being performed at the advanced avionics concept level as well as the subsystem level. In the efficiency area, the approach is to look at the system or subsystem from the operations view point, considering how to simplify and automate its operations.

6.1 STATUS OF CURRENT RESEARCH WORK:

Development of The Autonomous Operations (AUTOPS) testbed was started in late 1988. Architecture and design at the system level has been finalized, with major components and functions properly detailed (figure 3). The network protocols are being tested with initial interfaces to the data manager and the vehicle segment. Spacecraft system architecture development is continuing with functional details of each part being identified and documented. This architecture will be tested in the AUTOPS testbed when its initial configuration is complete.

Significant progress in the Autonomous Rendezvous and Docking (AR&D) area for the Pathfinder Program has been accomplished. This multicenter project has research work being performed in new sensor development, trajectory control requirements, new guidance and control algorithms and expert system applications. Several facilities with hardware and software mockups are in place at the Johnson Space Center (JSC) and Marshall Space Flight Center (MSFC) to analyze these operations in detail, and achieve significant effectiveness and efficiency in performing these operations.

Investigations in the area of trajectory control during a rendezvous and docking flight segment is continuing with the preliminary systems requirements document completed in October 1989. Mission scenarios for Mars Rover Sample Return and Satellite Servicer Systems were analyzed to derive requirements in the flight software component, as well as in the sensors and propulsion systems.

Guidance Navigation and Control (GN&C) algorithms development and testing is continuing in the areas of rendezvous and proximity operations. On-orbit operations knowledge capture has begun and the process is well underway to incorporate this knowledge into an expert system. Documentation of this knowledge and its implementation techniques is being performed at this time.

Vision algorithms and the associated hardware processing which are needed in order to perform autonomous docking operations have been identified. Control algorithms based on a fuzzy logic approach have been developed for the translational and rotational control of a spacecraft.

Techniques in system integration and testing that achieve efficiency and flexibility are being identified and applied in the areas of software integration. Comprehensive methods in verification and validation of software, including expert systems, is under development.

Although much more technology development is needed, a substantial amount of development work has already been accomplished in the tracking/vision sensors and processors at the JSC. Several techniques for the docking and tracking system have been analyzed, breadboarded, and evaluated in the laboratory. A laser rendezvous and docking tracking system is being developed for the Satellite Servicer System Flight Demonstration. Autonomous rendezvous and docking, and autonomous landing and hazard avoidance sensor studies are in progress as part of the Pathfinder Program. Also in development are a programmable 3D laser range/doppler imager and an associated processor, an optical image correlator, and a programmable image remapper to reduce the sensitivity of image correlation to scaling (target range) and rotation (target attitude).

Autonomous Landing is also a multicenter project with work distributed among Ames Research Center (ARC), Jet Propulsion Laboratory (JPL), and JSC, with JSC as the co-ordinating center in support of NASA Headquarters project management. The project requirement is to develop technology to land a planetary exploration spacecraft: a) close to the area of mission interest that may contain surface hazards such as large rocks and locally steep slopes, b) with a probability of safe landing greater than 0.98, yet without the payload penalty required for robustness against surface hazards, and c) autonomously.

Current activities are focused on the definition of requirements for landing accuracy and safety, a comparison of alternate navigation approaches for accurate landing, and a feasibility study of onboard hazard detection and avoidance. The requirements definition work this year is being accomplished by participating in the MRSR Phase-A Study.

An initial version of a model for computing the probability of safe landing as a function of lander robustness and hazard frequency has been developed. The addition of a hazard detection and avoidance function on the lander and information about the spatial distribution of landing hazards on planetary surfaces is needed in order to perform a tradeoff study between lander robustness, landing accuracy and on-board hazard detection and avoidance.

Linear Covariance analysis of navigation errors shows that the addition of radio range/integrated-doppler tracking from the descent vehicle of one or more beacons in orbit or on the ground improves the position accuracy to 0.5 - 2.0km. Landmark tracking using optical images, as is done in the cruise missile, should improve this accuracy. This landing accuracy is comparable to that estimated only from guidance errors by MRSR in Pre-Phase A. A complete simulation of the entry and landing GN&C is needed to identify any guidance and control development that is required to make such landing practical.

6.2 <u>KEY EXTERNAL/INTERNAL CONTACTS:</u>

K. Baker/EF5	Autonomous Landing
C. Gott/FM8	Autonomous Rendezvous
R. Kahl/IZ3	MRSR study
S.Lamkin/EH3	Autonomous Rendezvous & Docking Pathfinder Program
J. Lamoreux/EE6	AR&D and Landing Sensors
J. Moore/IA12	Satellite Servicer System
R. Savely/FR5	Artificial Intelligence

6.3 <u>FUTURE MAJOR MILESTONES:</u>

Tentative milestones for future work in the tracking and vision sensor activities are to review and evaluate the three types of technology (FY89-90) described earlier, develop the most critical and beneficial technologies/techniques (FY90-93), demonstrate autonomous rendezvous, docking, and proximity operations on the Satellite Servicer System Flight

Demonstration (FY93-96), and ground-demonstrate autonomous landing and hazard avoidance sensor/processor technologies and techniques (FY94-96).

Facilities that will support autonomous tracking system technology development and its demonstration include the JSC Tracking Test Bed with 6 degree-of-Freedom Precision Positioner, Cybermation robotic platform, Position Reference System, JSC Manipulator Development Facility and Air Bearing Floor Facilities at JSC and MSFC. These facilities are described in section 6.4.

Major milestones for development of an autonomous landing capability for planetary exploration are: 1) complete definition of requirements for precision landing and for on-board hazard detection and select approaches for development (FY90), 2) Verify landing accuracy using high fidelity simulation based on performance of prototype navigation sensors and guidance algorithms (FY94), and 3) 1G flight test to evaluate/demonstrate performance of on-board hazard detection system prototype (FY96).

Autonomous docking with the laser docking system will be studied in detail during FY90. Characteristics of the laser docking system under development in the Engineering Directorate will be modeled in the existing high fidelity six degree-of-freedom GN&C simulator in Mission Support Directorate to assess the integrated performance envelope and its impact on the guidance and control algorithms.

Detail testing of control algorithms based on fuzzy logic principles using 6 DOF simulation is planned for FY90. Development of a new algorithm that will use the vision measurements to track, approach and dock a payload will be initiated during FY90.

6.4 FACILITIES:

There are several facilities that support the detailed understanding of hardware and software at all levels: overall architecture of the advanced avionics, its components as well as subsystem level activities. The following facilities are used for the current research work performed in several areas:

1. Integrated Graphics Operations Assessment Laboratory (IGOAL)
2. Autonomous Operations Testbed (AUTOPS)
3. Tracking Test Bed/ 6-DOF Positioner
4. Hybrid Vision Laboratory
5. Manipulator Development Facility
6. Air Bearing Floor Facilities at JSC and MSFC
7. Contact Dynamics Simulation at MSFC

IGOAL facility

The IGOAL facility, located in Building 12 at JSC, is used for: a) systems engineering and operations analysis that requires man-in-the-loop interaction, and b) development of graphics software tools hosted on state-of-the-art graphics processors for real-time and non real-time operations assessments. It also provides capability to perform visual assessment of space operations and develop proper procedures for handling payloads. The visualization provided by elaborate graphics systems enhance the development of mission timelines with reduced time in moving a payload and yet simultaneously maintain proper clearances among the surrounding objects. The facility can also be used for properly understanding how proximity operations including berthing and deberthing are taking place and how these can be improved.

AUTOPS facility

The AUTOPS facility is designed to fully develop the advanced avionics concept from the systems view point. It is a test bed to check out all parts of the flight software component described earlier. The AUTOPS architecture directly supports distributed processing and allows testing of all types of hardware and software subsystems of a spacecraft. The AUTOPS testbed will be implemented on a network of workstations with proper interfaces to a graphics computer that will provide 3-dimensional visualization of space operations. It will be possible to test the performance of several advanced software technologies such as Expert Systems and their interfaces simultaneously.

For certain mission scenarios, the facility will provide real-time visualization of mission

operations. Real-time performance of the testbed will provide a capability to develop detailed operations procedures and identify important links and backup capabilities required to achieve efficiency. The testbed will be extensively used for: a) deriving performance requirements for intelligent sensors and effectors, b) assessing their impact on a mission timeline and overall operations, and c) assessing the performance of expert systems during mission.

Tracking Test Bed/6-DOF Positioner

The Tracking Test Bed is a 20 ft. wide x 300 ft. long indoor test range in Building 14 at the Johnson Space Center. This facility is used to develop and test various spacecraft onboard tracking systems, including a laser docking sensor and 2-D and 3-D machine vision systems. Within this facility, are a multi-camera based Position Reference System, two Cybermation remotely controlled robotic wheeled platforms, and a Six-Degree-of-Freedom (6-DOF) Positioner.

The Cybermation robots and Position Reference System are used to establish known two-dimensional relative motion between a tracking sensor and a target for coarse performance measurements.

The 6-DOF Positioner provides a means of precisely and dynamically simulating the relative position and orientation of a tracking sensor and a target. This capability will be used to precisely determine the dynamic performance of various tracking/vision systems in measuring range, bearing, attitude and associated rates. This system will be used to verify the performance of precision sensors for autonomous rendezvous and docking. The 6-DOF Positioner (figure 4) consists of three main subsystems: (1) a 12-meter granite rail which supports an air bearing table on which the sensor is mounted, (2) a mobile granite table on which the target is mounted, and (3) a 386/25 MHz controller processor, an IEEE bus controller, and a Global Positioning Satellite timing receiver to provide time tags for the various subsystems. The 6-DOF Positioner will provide angular accuracy of 0.001 degree and linear accuracy of 10 microns.

Hybrid Vision Laboratory

The Hybrid Vision Laboratory is a black-walled facility in Building 14 at the Johnson Space Center which houses an air suspension optics table with an extensive array of optical components and lasers. The laboratory supports development and testing of both digital and analog machine vision systems. These include a real-time optical correlator complete with cameras, monitors, spatial light modulators, and supporting computers and electronics. The laboratory also contains the Programmable Remapper image warping system, which is a video-rate geometric image transformation processor designed by NASA/JSC.

Manipulator Development Facility

This facility is a full scale mock-up of payload bay with one 'G' Remote Manipulator System (RMS) located in building 9A at JSC. There is a Systems Engineering Laboratory (SEL) computer to compensate for one 'G' earth environment effects so that the motion of RMS has a feel for orbital environment. (A real RMS will not work in one 'G' earth environment.) The facility is used for training the crew in the RMS operations with payloads and in developing procedures and timelines.

JSC Precision Air Bearing Facility (PABF)

This facility has been in service since 1976. It provides the capability for reduced friction simulations of zero gravity in support of development of hardware and operational procedures for NASA spaceflight programs.

The air bearing table is 24 feet in length by 21 feet wide. The twenty-one 6 inch thick steel plates that comprise the table are precision ground to a tolerance of 0.0005 inches over any arbitrary 2 foot by 2 foot section. The entire table can be leveled to within 0.011 inch. This degree of precision permits a unit under reduced pressure, thus minimizing the skating effect commonly encountered in similar facilities. The steel construction of the bearing surface endows it with great durability. The surface, as cast, has a Brinnell hardness of 180 to 220, offering a high resistance to scratching and gouging.

The PABF has been employed in Manned Maneuvering Unit (MMU) testing, evaluation, and flight training. Its sensitivity allows the evaluation of dynamic responses to disturbances induced by factors such as crew limb motion and umbilical/tether dynamics.

MSFC Teleoperator and Robotics Air Bearing Floor

The air-bearing floor is a 4200-square-foot precision cast epoxy isolated pad on which full-scale mockups of spacecrafts, structures and modules can be floated on air bearings. A six-DOF mobility unit operates under closed loop remote control to allow accurate, repeatable positioning of high fidelity instrument/video/capture mechanisms (weighing up to 400 pounds) in order to simulate rendezvous and docking maneuvers with full-scale mockups under controlled variable lighting conditions. Full video and telemetry are returned via RF link. A payload mounted on this simulator can represent a moving satellite during docking simulations. Additional air bearing and stationary stands are available for mounting targets on or about the flat floor. Free body dynamic models of motion are run on a VAX computer to control and direct the mobility unit and the dynamic target simulator.

MSFC Contact Dynamics Simulation

The MSFC Contact Dynamics Simulator is a hydraulically driven, computer controlled, six-degree-of-freedom simulator. The facility can handle payloads up to 20,000 pounds and accelerations up to three G's. The dynamics of two bodies are represented in the simulation, and most vehicle motions can be provided, including spinning, coning, and tumbling. The simulation includes the characteristics of the vehicle control system, structural dynamics, and manual control. Some of the safety features provided include pneumatic positioning of test articles to prevent excessive contact forces, breakaway bolts, and software limits on forces and moments. These features protect the test articles during simulations.

7. TECHNOLOGY NEEDS AND HOLES IN THE ACTIVITIES:

The research work and progress in this area of autonomous spacecraft control is not complete nor comprehensive. Certain flight segments have received particular emphasis in anticipation that the results will be applicable across a range of programs. It is also expected that the technology developed in these areas will be useful in the areas where research work is at low level.

Current activities in the Fault Detection, Isolation and Recovery (FDIR) techniques are at a very low level and assume that the system being implemented will be on the ground and not on the spacecraft. It should be emphasized that these FDIR systems will have to be onboard for Lunar and Mars missions, and that they must provide reliable performance. Furthermore these systems must work within the framework of autonomous operations and its architecture.

There is a low level of activity in the autonomous ascent, traffic management and debris avoidance areas. However, these activities are not closely tied in with the activities in AR&D, Autonomous Landing, Vision/tracking systems, and AUTOPS and IGOAL facilities. From the view point of autonomy, there should be more information exchange and cooperative plans.

For a complete development of autonomous spacecraft control, there should be a well designed testbed that allows an evaluation of the software and its integration with the hardware as a total system, and that considers the performance of the system from an operations point of view. An extensive amount of expert knowlege capture needs to occur in the software area in order for autonomous spacecraft control to reach fruition. For each of the four mission segments (ascent, rendezvous, proximity operations, and landing), the onboard software must be able to plan and as well as properly execute trajectory maneuvers. During a mission, circumstances may not allow the engineers on the ground the opportunity to plan each segment and then to provide the spacecraft with the necessary information.

Several facilities with unique hardware and associated software are in place or becoming in

place. There should be a comprehensive plan either to tie all these facilities and activities into one testbed or to implement sufficient overlap for smooth transition from one facility to another. This will enable migration of autonomy onboard the spacecraft at a faster rate.

The distinction between automated and autonomous operations is not clearly understood at management levels, much less the cost and benefits of autonomy. As a result, the development of applications is postponed until it is really required for completing the mission. Applications are then developed with no emphasis on operational efficiency. The end result is very high operational cost or no cost effectiveness. Unless more emphasis is placed on the development of technologies for autonomy, near Earth operations will continue to be inefficient and unmanned remote operations will not be feasible or will meet with decreasing mission success.

Most of the basic technology required for autonomous spacecraft control exists today in unintegrated and small rudimentary applications form. Onboard task planning and management systems, intelligent GN&C systems, advanced sensors, and intelligent effectors are all being worked, albeit at an immature level. What is required, consequently, is a system integration that is targeted towards specific functions and capability. Currently, this integration activity is performed only when it is absolutely needed by a program. There is an understandable reason for this behavior: initial development of applications is driven by budgetary constraints and needs, rather than by completeness of applications. As an example, the vision algorithms have been developed for computing relative attitude angles, but they are not integrated into space operations because no program absolutely requires or has plans to use them.

In the tracking sensor area, one of the most promising, but least mature technologies is robotic vision. Robotic vision has great potential for autonomous operations such as inspection, grappling, docking, berthing, surveillance/traffic management, and landing. Better sensors are needed, including 3D laders, optical image correlators, and digital processing algorithms for 2D and 3D imagery.

8. SUMMARY

Improving the operational efficiency of current programs and satisfying the operational requirements of new programs will require new technologies for autonomous spacecraft control. Additional benefits and efficiencies can be achieved by common usage of spacecraft control hardware and software across multiple programs.

Until there is a high level commitment and associated multiyear funding for autonomous spacecraft control, the activities performed in these areas will not result in a tangible benefit for the space program. Cost effectiveness and operational efficiency for space operations will not be achieved nor the long range Lunar and Mars missions without this autonomy onboard the spacecraft.

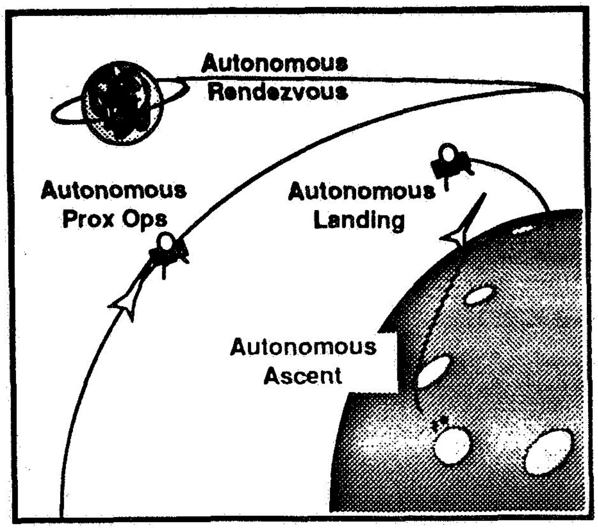

FIG. 1 Flight Segments for Autonomous Spacecraft Control

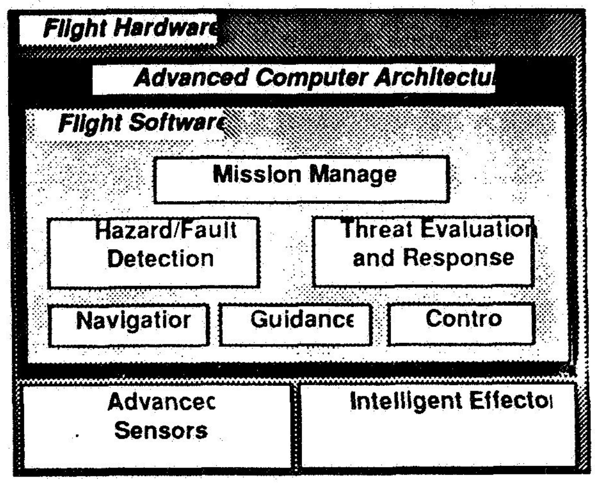

FIG. 2 Components of Advanced Avionics System

TABLE I. CANDIDATE PROGRAMS AND TECHNOLOGY UTILIZATION

REPLACEMENT (Substitutive)	ENHANCING (Complementary)	ENABLING (Essential)
NSTS	NSTS	
SSF	SSF	
	OMV	
	ACRV/CERV	ACRV/CERV
	Satellite Servicer System	Satellite Servicer System
	OTV	
	Advanced Launch System (ALS)	
	AOTV	AOTV
	Manned Lunar	Manned Lunar
		Mars Rover Sample Return
		Manned Mars

TABLE II. AREAS OF AUTONOMOUS CONTROL VS. PROGRAMS

Candidate Programs

Functions	NSTS	OMV	SSF	ALS	CERV/ACRV
Autonomous proximity operations and docking	Enhancing	Replacing/ Enhancing	Replacing/ Enhancing	____	Enhancing/ Enabling
Autonomous Rendezvous	Enhancing	Replacing/ Enhancing	____	____	
Autonomous Landing	Enhancing	____	____	____	Enhancing/ Enabling
Autonomous Ascent	Replacing/ Enhancing	____	____	Replacing/ Enhancing	____
Traffic Management	____	____	Enhancing	____	____
Debris Avoidance	____	____	Enhancing	____	____

TABLE II. AREAS OF AUTONOMOUS CONTROL VS. PROGRAMS (continued)

Candidate Programs

Functions	SSS	MRSR	Shuttle-C	OTV/AOTV	Lunar Base & Manned Mars
Autonomous proximity operations and docking	Enabling	Enabling Enabling	Enhancing/ Enabling	Enhancing/	Enhancing
Autonomous Rendezvous	Enabling	Enabling Enabling	Enhancing/ Enabling	Enhancing/	Enhancing
Autonomous Landing	____	Enabling	____	____	Enhancing
Autonomous Ascent	____	Enabling Enabling	Enhancing/	____	Enhancing
Traffic Management	____	____	____	____	Enhancing
Debris Avoidance	____	____	____	____	____

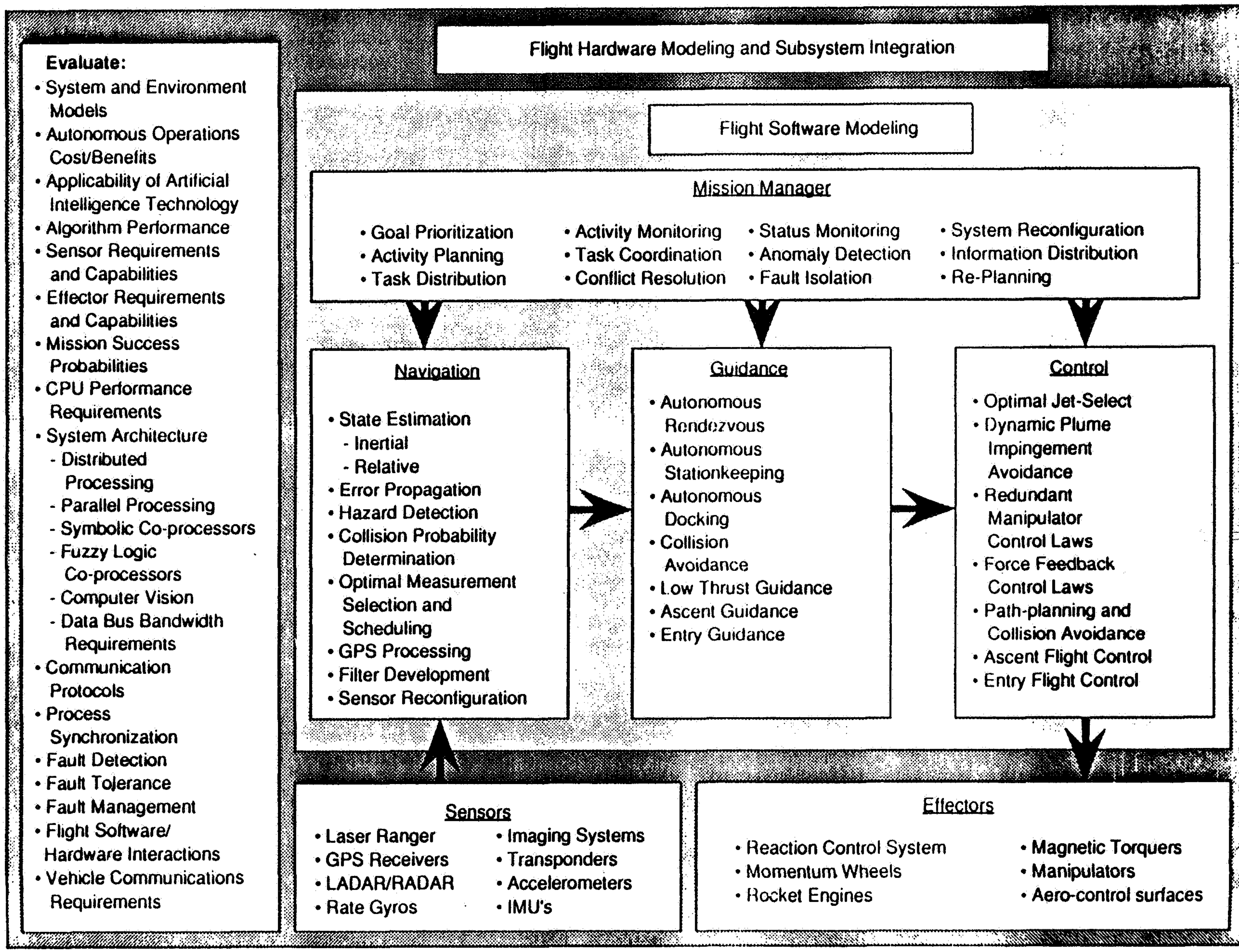

Figure 3 DETAIL ARCHITECTURE OF AUTOPS TESTBED

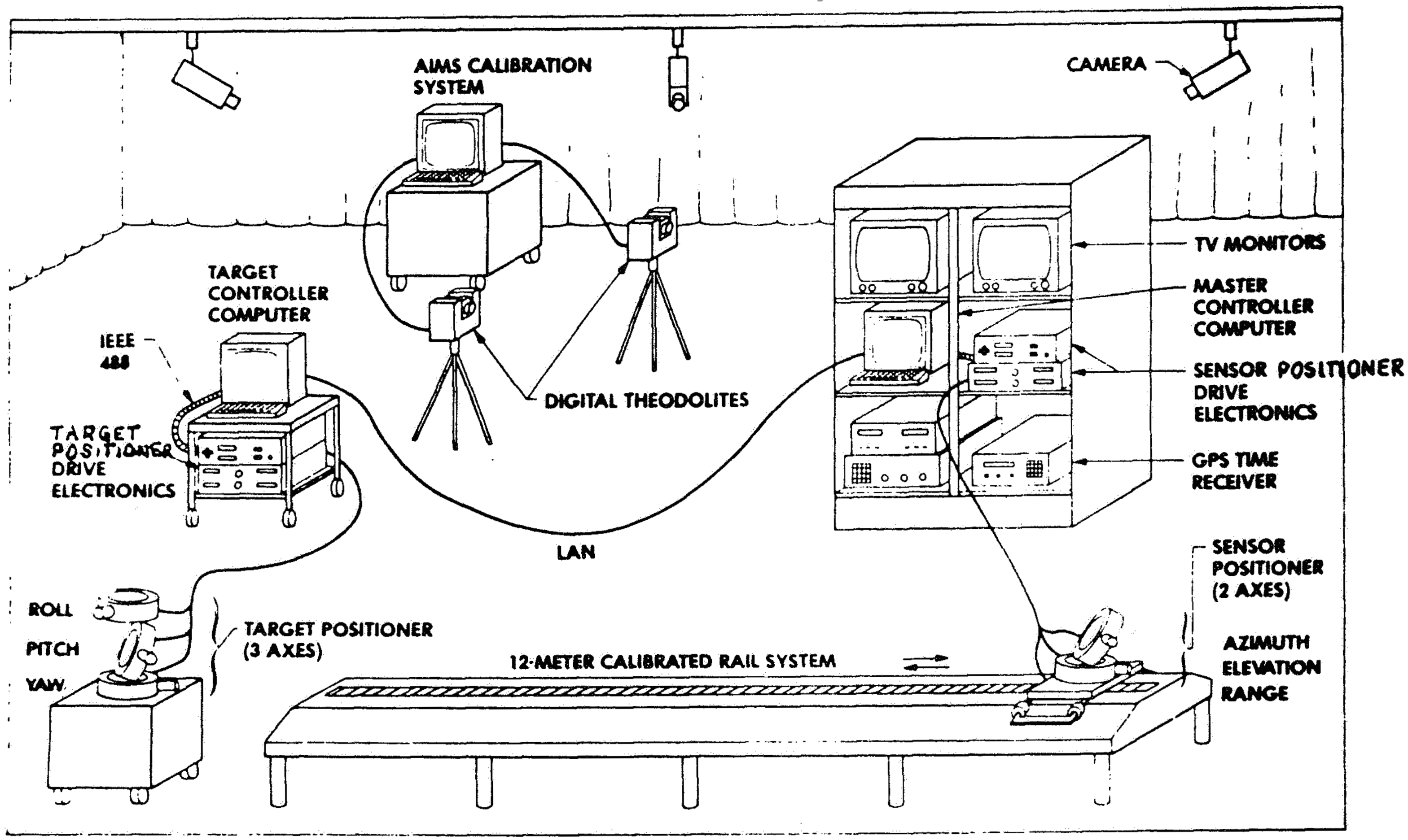

Figure 4 SIX DEGREE-OF-FREEDOM FACILITY

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OPERATIONS MANAGEMENT SYSTEM

SPACE TRANSPORTATION AVIONICS
TECHNOLOGY SYMPOSIUM

WILLIAMSBURG, VA.

NOVEMBER 7-9, 1989

OPERATIONS MANAGEMENT SYSTEM

WHITE PAPER

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1.0 INTRODUCTION

The trend over the past decade, in the aeronautics and astronautics fields, is to provide increasing amounts of synthesized data for the human controller of a flight vehicle. One would expect this demand to continue on into the future. The major impetus for this trend is the continued distribution of computing capability to support integrated command and control of flight vehicles. This has given rise to the concept of an "operations management system". The definition of an operations management system, as used in this paper, is "that hardware and/or software which is responsible for the integrated operational control of aeronautic and astronautic distributed flight systems". This reflects the industry trend in avionics system engineering and integration (SE&I) toward operationally managing increasing amounts of data from an increasing number of sources, interpreting the data and using it in decision support systems for the operator. This is happening in the commercial and military aircraft business as well as in the manned and unmanned spacecraft business. When one peruses the literature one finds such titles as "vehicle management systems", "flight management systems", "cockpit management systems" and "mission management systems". They all have in common, the goal of providing an operational capability to manage this increasing volume of data without overwhelming the pilot, astronaut or automated control system.

2.0 OBJECTIVES

The overall objective of an operations management system is to provide an orderly and efficient method to operate and maintain aerospace vehicles. The purpose of the system is to aid in commanding and controlling the vehicle systems, whether distributed or centralized, in an integrated manner. This can be done in such a fashion that total vehicle status and response can be quickly understood and controlled. An operations management system must be built such that it and the other vehicle systems can evolve to support a flight program which may last for thirty years. For example, a particular automation technique may first be used under direct operator control, and later, as confidence is gained in the technique it would be allowed to function autonomously. Considerable production and operational efficiencies can be achieved by using modular and standardized software structures, common user controls, and standardized procedures shared by several vehicles. The achievement of commonality of design and control for all future aerospace vehicles requires continual emphasis in order to achieve significant reduction in our budgetary and human resources.

3.0 OMS PROVIDES THE FRAMEWORK FOR INTEGRATED COMMAND AND CONTROL

The fundamental philosophy behind the implementation of an operations management system is to perform as much processing as possible at the lowest architectural levels. This approach facili-

tates efficient use of a distributed information systems resources and provides the requisite flexibility to support operations as procedures change and when new system components are added or replaced. A Space Station Freedom (SSF) Operations Management System (OMS) is being designed which provides integrated command and control through a hierarchical architecture consisting of three levels or tiers. The tier structure can be thought of as being analogous to a classical business organization. Tier I is the high-level executive function. At this global level, general operating policies are enacted and enforced. For SSF, the flight crew, ground control centers, and OMS constitute Tier I.

Tier II is the line management, working largely autonomously to carry out utility systems and facility level functions and to fulfill the global requirements set at Tier I. Constituents of this architectural level include the distributed executives for systems such as Electrical Power, habitat and laboratory modules, and attached payloads. This level offers the possibility of accommodating future independent module operations, constrained only by the global oversight of Tier I.

Tier III is where subsystem and component operations and control occur. Denizens of Tier III include the so-called "smart" components, equipment racks, and payload groups. During operations, Tier III receives compact, concise instructions and commands are passed down from Tier I through Tier II. In the course of passing through each level, the command is successively "decomposed" into specific instructions directed to the appropriate target executives and components. Thus, the a terse Tier I instruction such as,"Perform a reboost in one hour" spawns hundreds of successor commands that propagate down through Tier III for ultimate execution.

These commands direct tasks such as targeting the burn, configuring the flight control system to support powered flight, configuring and verifying readiness of the propellant subsystems and securing payloads and experiments so that they can withstand the anticipated acceleration. In a corollary fashion, data from the lower architectural levels is synthesized as it negotiates its way to the top. Tier III components will typically be dealing with micro-instructions and data in terms of register contents and similar machine-specific constructs. In the case of a SSF reboost, Tier III might send a rather detailed accounting of their status to Tier II (but still less detailed than what exists at Tier III). What survives of this data when it reaches Tier I might be a simple "Go/No Go" statement of system readiness. This hierarchical approach to operations management, monitoring, command and control maximizes the efficiency of data processing and communications resources. The multi-tiered structure optimizes the interface at each level. Thus Tier I transactions are inherently amenable to the natural language constructs of the User Interface Language (UIL), while the machine-specific instructions at Tier III are best handled by the components at that level. Localizing the man-machine interface to a single architectural

level produces significant gains in human productivity while lowering training requirements and reducing exposure to procedural misunderstandings.

4.0 TECHNOLOGY ISSUES

Greater efficiency in the development and maintenance of aerospace vehicles utilizing operations management system approaches, requires meeting specific technological goals. These goals include advances in software development techniques and computer hardware capabilities.

Sound software engineering techniques need to be developed to allow production of code that is flexible, easy to share among diverse applications and inexpensive to build and maintain throughout its life cycle. An advanced software engineering development environment will increase the efficiency of code production, much like the use of spreadsheet programs increases the efficiency of financial and engineering calculations. Increased efficiency of code generation can be achieved through the use of expert systems-based tools that optimize software structures and aid the engineer in assembling applications from libraries of component software parts. Strong systems engineering, at the beginning of a program, can produce software products that are useful for a host of applications across other aerospace programs.

Standards for computer hardware need to be developed along with computers capable of interacting with other computers in an heterogeneous environment of hardware types and multiple software languages. Experience has shown that, despite the existence and use of standards, there is always a need for heterogeneity.

Experience with the use of expert systems and other advanced automation software techniques needs to be widened to the extent that enough engineering confidence is gained with them so that they will be utilized for command and control. Methods need to be developed to harness these techniques to achieve increasingly effective and efficient interactions between man and machine and interactions among machines. An increased emphasis is required on making these command and control interactions generic enough to be valid and useful across a variety of future aerospace vehicles and for upgrades to present vehicles.

5.0 RECENT DEVELOPMENTS IN OMS COMPONENTS

A conceptual architecture design activity for the integrated commanding of hierarchical distributed systems began at the NASA JSC in 1985 as a study for the Mission Operations Directorate (JSC 20792). This study provided the basis for the SSF onboard portion of the OMS. The final phases of this study coincided with the beginning of the OMS Working Group, which first met in early 1986 and provides the forum for discussions and dissemination of information related to design and implementation of the SSF OMS.

Standalone component prototypes were developed in Zeta Lisp on the Symbolics. A Procedures Interpreter (PI) component illustrated the use of different levels of automation in the execution and monitor of crew procedures. An Integrated Status Assessment (ISA) component performs failure analysis based on integrated models of the SSF utility systems. These components were first demonstrated in October 1986.

For other NASA programs several expert system based components have been developed and are in use to perform intelligent monitor and diagnosis of manned and unmanned systems operations. The Integrated Communications Officer (INCO) Expert System has been installed in the Mission Control at JSC, and is used by flight controllers during Naational Space Transportation System (NSTS) operations to perform automated monitoring of the communications equipment. The success of INCO has resulted in a number of similar projects that incorporate advanced automation in other flight control positions in Mission Control. Similarly, the Spacecraft Health Automated Reasoning Prototype (SHARP) is used at the Jet Propulsion Laboratory to perform automated health and status analysis. They are using SHARP for multi-mission spacecraft and ground data systems operations, with its initial focus being on the telecommunications link of the Voyager II spacecraft. Another application, that began as a proof-of-concept prototype and is finding use in operations, is the Maintenance Operations Management System (MOMS). MOMS uses advanced graphics and video techniques to assist in the execution of onboard maintenance procedures. MOMS is currently being installed in the Mission Support Room at JSC for use on the NSTS. Other expert system prototypes are also in development in the areas of flight plan generation and replanning and in fault diagnostics.

6.0 MAJOR ACCOMPLISHMENTS IN OVERALL SYSTEM DESIGNS

An operations management system represents the highest level of control in any hierarchical distributed environment. Space Station Freedom represents one such environment, although there are other examples, such as the command and control of deep space probes. Aspects of technology that are used in an operations management system include system health analysis, command and control, and plan generation and execution. An operations management system involves not only the real time aspect of operations, but also the support activities that make it possible to use advanced automation in real time control.

The SSF OMS Integration Group, at the Johnson Space Center (JSC) was formed in September 1987 to organize the effort to integrate prototype OMS software with other SSF system simulations. The OMS Integration efforts primary goal was to demonstrate an OMS integrated command and control architecture. This has been demonstrated in a phased manner, with the OMS prototype commanding a Guidance, Navigation and Control simulation with respect to global commands ("start the reboost"), while GN&C performs system specific functions("turn on jet 2"). The OMS prototype coordina-

tes appropriate global activities ("prepare all systems for reboost"). Phase Two, currently in test, saw the migration of the OMS prototypes from a Symbolics to a VAX computing environment, and the addition of more functions and simulations. Thermal Control, Communications and Tracking, Electrical Power have been added to the original reboost scenario along with a SUN hosted node representing the ground control segment of the OMS. Also added was a VAX-based Display and Control node representing the displays a crewperson would use when interacting with the OMS.

Future demonstrations have been planned that add more simulation nodes, especially for payloads, and add functions to the OMS node, extending both horizontal and vertical integration. This work has been planned through 1991. The additional OMS functions include the handling of the onboard short term plan, additional failure diagnosis, and contingency replanning functions. Other operational concepts involving an OMS are being studied such as the handing off of control between a onboard based OMS and a comparable ground based system.

The scope of the work addressed by the OMS Integration Group will expand beyond the single SSF manned base in efforts past the 1991 time frame. For example, the use of the OMS to coordinate SSF and NSTS joint operations will be investigated where Test Bed nodes represent involved systems and trajectory dynamics. Eventually, the effort will migrate to a computing environment that is more flight-like by using prototype onboard hardware at the representative nodes and executing flight type applications software.

7.0 SIGNIFICANT FUTURE MILESTONES

Figure 1 (Key Technologies For OMS Future Development), shows two technology areas, Expert Systems and Man-Machine Interfaces, which are key to the future development of an OMS. In addition, this figure identifies the new NASA programs which could benefit from these technologies. Advancement of the technology is divided into three areas of sponsorship; Research & Technology (R&T), Advanced Development and program level Design, Development, Test & Evaluation (DDT&E). The sponsor for each of these areas would carry the technology development through some level of completeness. These completeness levels, as defined by the Office of Aeronautics and Space Technology (OAST), are identified in the table below.

DDT&E	Level 7	Engineering Model in Space
Advanced Development	Level 6	Prototype/Engineering Model Tested
	Level 5	Component/Brassboard Tested in Relevant Environment
	Level 4	Critical Function/Characteristic Demonstration

R&T	Level 3	Designs Tested Analytically or Experimentally
	Level 2	Conceptual Design Formulated
	Level 1	Basic Principles Understood

Each of the technologies in Figure 1 would be applied to fundamental operations management tasks (i.e., planning, diagnosis or system control) which are performed by the system to assist the human operators.The expert systems technology for control of complex dynamic subsystems will evolve from control of single sub-systems in the early Space Station era to hierarchical control of multiple sub-systems later, and to distributed control of many subsystems in the Mars Transfer Vehicles. As the expert system capabilities evolves, and as confidence increases, less human interaction and monitoring of the system will be required. This will free-up onboard crewperson time and reduce the number of ground support people. Man-Machine Interface (MMI) development must parallel the evolution of the expert system technology. Even though an automated capability may be controlling, the user must be provided with sufficient information to assess the state of the system and be allowed the option of manual override at any time without delay. The essence of the MMI is to permit the system to smoothly transition between operator control and automated control.

Expert Systems for monitoring and control of space hardware has been under development for several years at NASA centers. An important subset of this technology will be Fault Detection, Identification and Reconfiguration (FDIR) for flight hardware. The Ames Research Center (ARC) and the JSC, as part of the R&T base, have jointly developed a thermal control hardware expert system called TEXSYS. They are also formulating an electrical power Control expert system called PMACS. Later systems will combine individual subsystem controllers into multi-subsystem monitors which will allow coordinated control of an entire complex of space hardware. The Integrated Status Assessment (ISA) tool which is part of the SSF OMS integrated test bed at the JSC is an example of a global level expert system. Another major application of expert system technology is in the space mission planning and scheduling. In previous space programs, planning and scheduling was a manual task requiring a considerable staff of highly specialized people. Today, sophisticated software systems are being applied to the planning and scheduling tasks, but they are more of an aid to the planners rather than a substitute. Future systems will contain the added capability to recommend and suggest options and produce a conflict free mission plan containing a multitude of activities and constraint parameters. Work is underway at the GSFC and at the JSC, using the R&T base, to develop expert planning systems. The GSFC is currently performing proof-of-concept testing on a planning system called the Scheduling Concepts, Architecture and Networks (SCAN),for NASA operated free flyer space platforms.

Procedures and checklists have always played an important role in the operation of aeronautical and astronautic systems. For future systems, these procedures will still exist, but in a different form. For SSF and other new manned flight systems, the procedures will be in executable electronic form, permitting execution to be accomplished in a near manual step-by-step process, in a semi-automatic process where the computer and operator share in the execution of sequential steps, or fully automated where the operator gives permission for the computer to execute the procedure and the operator monitors. Prototypes of these procedure executors are being developed at the JSC for SSF as part of the SSF OMS integrated testbed activities under the SSF DDT&E. Systems currently in development use conventional keyboard and mouse devices for manual interaction. Future systems will use natural language interfaces and utilize higher level input devices such as voice recognition systems.

Development work underway within the NASA to produce advanced man-machine interfaces include the Operations and Science Instrument Support (OASIS) command and control system software created at the University of Colorado at Boulder Laboratory for Atmospheric and Space Physics (LASP). This system was originally created for remotely controlling the Solar Mesophere Explorer (SME) which was an earth-observing satellite that measured parameters related to ozone levels in the atmosphere. OASIS is now being used as the basic MMI structure for SSF OMS prototype development.

8.0 SUMMARY

This paper has described concepts for an operations management system and has highlighted the key technologies which will be required if we are to bring this capability to fruition. Without this automation and decision aiding capability, the growing complexity of avionics will result in an unmanageable workload for the operator, ultimately threatening mission success or survivability of the aircraft or space system. The key technologies include expert system application to operational tasks such as replanning, equipment diagnostics and checkout, global system management, and advanced man-machine interfaces. The economical development of operations management systems, which are largely software, will require advancements in other technological areas such as software engineering and computer hardware. Also, added emphasis on systems engineering and integration, early in the design phase, will result in systems which are flexible and expandable. Accomplishment of the above technological tasks consists primarily of emphasizing and strengthening existing efforts. Some basic research and development is ongoing in each of the areas identified. What is missing, is a focus and unified effort to apply these technologies to the operations management system problem.

9.0 KEY CONTACTS

The following personnel are currently involved with the development of operations management system capabilities.

A. E. Brandli, NASA-JSC,
R. E. Eckelkamp, NASA-JSC
J. B. Hartley, NASA-GFSC
L. Henschen, McDonnell Douglas Space Systems Company-Space Station Division
C. M. Kelly, The MITRE Corporation
W. McCandless, Lockheed Engineering & Sciences Company
K. Moe, NASA-GSFC
D. L. Rue, TRW, System Development Division

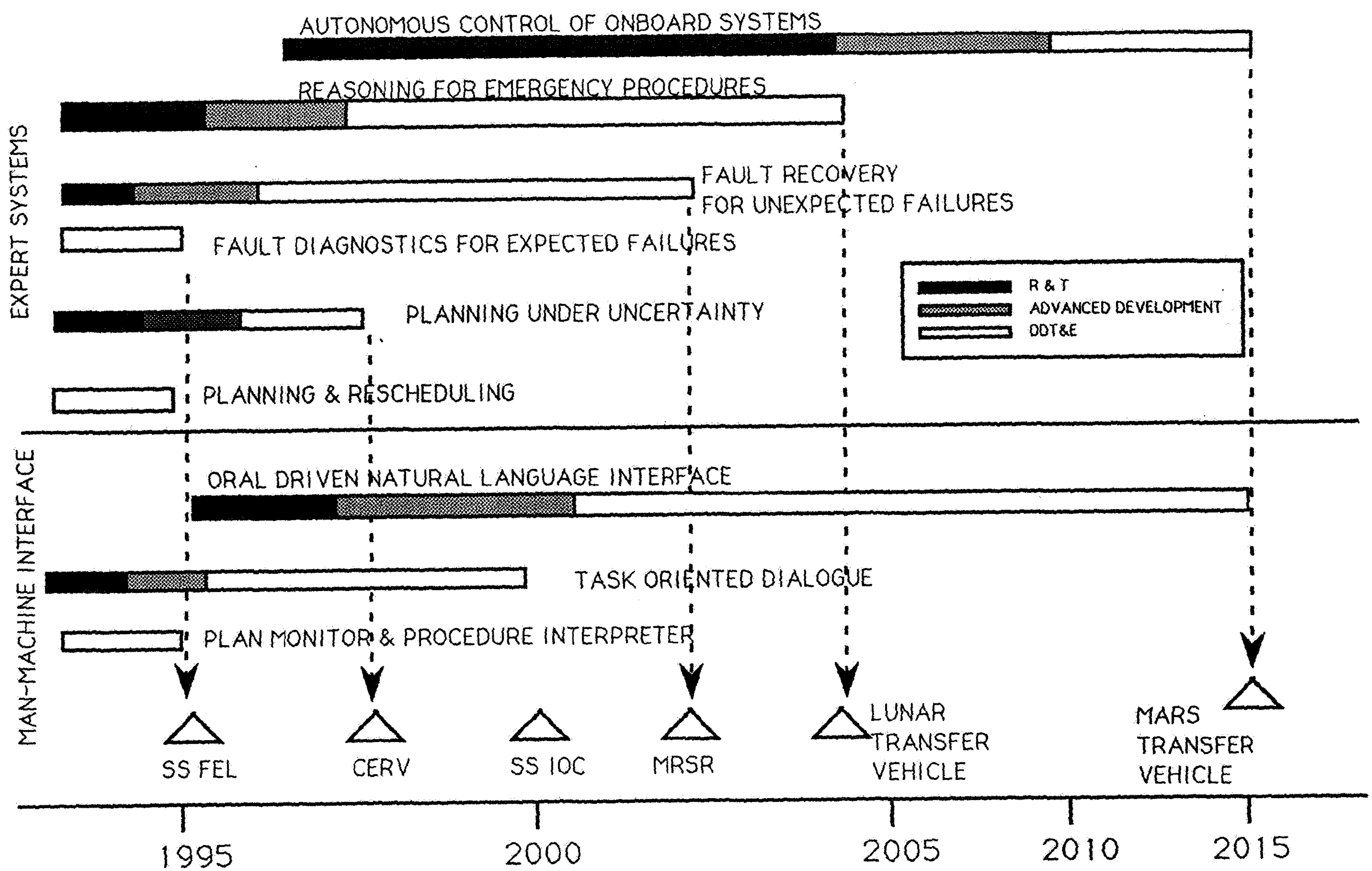

FIGURE 1-KEY TECHNOLOGIES FOR OMS FUTURE DEVELOPMENT

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OPERATIONAL EFFICIENCY SUBPANEL
ADVANCE MISSION CONTROL

STATS White Paper

Operational Efficiency Subpanel
Advanced Mission Control

Peter Friedland
Ames Research Center

Introduction

For purposes of this paper, the term "mission control" will be taken quite broadly to include both ground- and space-based operations as well as the information infrastructure necessary to support such operations. The paper will focus on three major technology areas related to advanced mission control. These are:

- **Intelligent Assistance for Ground-Based Mission Controllers and Space-Based Crew**: computational systems that increase human performance and reduce training time--this area will be referred to as IA for the remainder of the paper

- **Autonomous Onboard Monitoring, Control and FDIR**: computational systems that are independently able to montor, control, diagnose, and repair onboard systems when humans are unavailable or incapable of performing under the applicable realtime constraints--to be referred to as AOM

- **Dynamic Corporate Memory Acquired, Maintained, and Utilized During the Entire Vehicle Life-Cycle**: methods for acquiring, storing, preserving, and utilizing knowledge of many forms that is gained during design, construction, testing, and operations of a vehicle and provides an important basis for effective mission control--to be referred to as CM.

While only the first area falls within the traditional purview of mission control, all three contribute substantially to a truly efficient total system for operations of the Agency's next generations of space vehicles.

The paper will survey the current state-of-the-art both within NASA and externally for each of the three technology areas and will discuss major objectives from a user point-of-view for technology development. Ongoing NASA and other-governmental programs will be described (including approximate dates of readiness for operational Agency use) along with key contacts and facilities (both existing and planned). An analysis of major research issues and current "holes" in the program will be provided. Finally, the paper will present several recommendations for enhancing the technology development and insertion process to create advanced mission control environments.

Current State-of-the-Art

Within the IA area, NASA is considerably behind the industrial state-of-the-art. This is an area that has seen enormous advances both in hardware (moving from main frame driven alphanumeric displays to powerful individual workstation utilizing bit-mapped graphic displays) and software (with thousands of fielded knowledge-based systems and recent developments in hypercard and related technologies). While the Agency has several ongoing efforts to update information management for human mission controllers (some are described below), it still uses technology that has not advanced significantly since the 1960's in many cases. The contrast to industrial practice is seen best by comparison to off-the-shelf systems being produced by companies like Measurex to provide "mission control" to highly automated factories. The key point here is that, in this author's opinion, within the ground-based IA area there is little need for NASA to lead in developing new technology, but instead should concentrate on upgrading to the very best of current industrial standards.

For space-based systems there is little industrial or governmental precedent (mainly because we have only modest amounts of space-based "mission control" at the present). For crew on STS, complex procedure manuals and the radio link to help on the ground serve as their major information sources. Perhaps the best known work to improve the state-of-the-art here is the Pilot's Associate Project sponsored by DARPA and the Air Force. Several projects to build intelligent assistants for crew are described below; NASA should clearly lead in this area, particularly as it moves to human exploration missions where the link to the ground is far more tenuous than it is today.

Within the AOM area, both NASA and outside industry rely mainly on conventional algorithmic methods for monitoring and control with few, if any, operationally fielded autonomous systems capable of complex diagnosis and repair (even if solely by reconfiguration). The "conventional" systems can be quite complex (e.g. the systems that control STS ascent), but are poor at reacting to unpredicted events outside of a narrow mission envelope. Considerable basic research has been accomplished over the last ten to fifteen years to improve this situation. The growth of work in "model-based reasoning" within the artificial intelligence field is an attempt to expand from experience-based heuristic methods (commonly known as expert systems) to systems that are capable of reasoning from first principles of science and engineering to accomplish control and diagnosis in real time. NASA is currently among the leaders in work in this field (see below) and should continue its efforts with increased emphasis on technology insertion projects as the basic work matures.

The CM area is viewed by many in the computer science community as one of the next great challenges to the field. The goal here is to expand upon current data base and knowledge base technology to allow for the automatic creation of information systems several orders of magnitude beyond those in current use. A current example of a NASA information system is the Space Station Freedom Technical and Management Information System (TMIS). Ideally TMIS would encapsulate all of the design, construction, testing, and operations knowledge (both formal and anecdotal) from dozens of contractors

and thousands of engineers in a form that is maintainable and useable (both by humans and by automated systems) for the thirty-plus year life span of SSF. Practically TMIS will be a massive document indexing and retrieval system utilizing mainly current data base technology. This does represent the state-of-the-art in the field. Efforts (some described below) are underway to improve those conditions, but NASA, because of its nearly uniquely complex and long-lasting information requirements, is in the ideal position to lead new initiatives to improve the state-of-the-art in this area.

Objectives

Each of the three technology areas has several objectives that relate to improving mission control environments within NASA. For the IA area the major objectives are:

- **Reduced manpower needs**: current STS operations require over 400 support personnel in the FCR and back rooms. Round-the-clock SSF operations over thirty-plus years will impose a manpower problem (and therefore a cost problem) of massive proportions unless technological improvements make a substantial contribution. The objective here is to automate as many of the back room functions as possible as those personnel serve mainly in information gathering roles for FCR officers who make critical decisions.

- **Reduced training time**: current systems require two years or more of extensive training to turn a novice controller into an expert. Much of that time is needed to explain abstruse displays and terminology to engineers already versed in actual vehicle structure and functions. Systems that can deal with trained engineers in closer to the normal language of engineering (schematic diagrams, technical English, etc.) already show strong potential for major reduction of the training period.

- **Improved critical decision-making**: current systems present too much information at a single cognitive level during periods of critical, time-limited, decision-making. Intelligent assistants that can highlight and focus attention will provide substantial improvement in human performance (in essence this is the major theme of the DARPA/Air Force Pilot's Associate Project--allow the crew to focus on the crisis at hand).

For the AOM area the major objectives are:

- **Free crew to conduct mission tasks**: if automated systems can be built to monitor and control routine onboard subsystem operations (e.g. power, thermal, communications) and to find and in some cases even correct failures, then crew can be freed to conduct the real business of reactive space science and exploration. This will greatly enhance the effective return of major Agency missions. As an interesting note, an informal, but

substantial survey of crew done for the SSF Level I Study on Advanced Automation showed that crew were overwhelmingly in favor of automated systems that would allow them to become productive scientists and engineers rather than "on-off switch flippers" for Space Station Freedom missions.

- **Provide realtime capabilities beyond human performance levels:** for many subsystems, humans simply cannot react fast enough for major classes of control and fault-correction situations. Any enhanced capabilities beyond those currently available from algorithmic control will contribute substantially to crew safety and mission performance.

- **Enhanced mission safety by discovery of incipient failures:** humans are notoriously poor at tracking thousands of engineering parameters over dozens or hundreds of days. Some onboard problems occur with little warning, but, in theory, many could be found in the anomaly, as opposed to failure, stage by diligent, autonomous analysis of all telemetry data, carefully looking for trends that may lead to failure.

For the CM area the major objectives are:

- **Capture, represent, and maintain knowledge throughout design, construction, test, and operations:** ideally a corporate memory system would acquire knowledge routinely throughout a vehicle's entire life cycle. It is important to note that the oft-repeated Agency goal of "Design Knowledge Capture" tends to obscure the fact that design knowledge is only part of the information that can lead to efficient operations since enormous amounts of practical information are gained later in the life cycle, and that knowledge capture is only part of making information useful (after all, the tens of thousands of pages of engineering documents "capture" knowledge, they just do not make it practically available to problem-solvers).

- **Automatically provide focused problem-solving capability:** a long-term objective is to provide the ability to automatically "compile" specific problem-solving systems from a generic corporate memory. This would allow the same information to be used effectively in several different problem-solving contexts, e.g. diagnosis and re-design without the current process of expensive "hand-crafting" of knowledge-based systems. While it is unlikely that this objective will be met within the short-term, basic research results sponsored by NASA have already shown the concept to be viable.

Ongoing Activities

Three NASA programs are conducting research and development activities in the technology areas described above. In OAST, the CSTI Artificial Intelligence Program (run by Code RC, the Information Sciences and Human Factors Division) is responsible for basic scientific research, applied engineering development, and significant amounts of applications prototyping in all three areas. In fact, the IA, AOM, and CM areas make up about 75% of the entire Program, and much of the remaining portions of the Program deal with engineering telemetry analysis, of clear peripheral relevance to the three areas discussed here. Basic research in planning, scheduling, knowledge acquisition, cooperating intelligent systems, machine learning, and large-scale knowledge base technology is conducted at ARC and its associated grantees and contractors, and at JPL. Engineering development of tools for scheduling, modeling and simulation of complex Agency devices, integration of symbolic and numeric control methods, and man-machine interaction is conducted at ARC, JPL, JSC, and MSFC. Prototype and fielded applications for existing mission control environments (e.g. MCC at JSC, Firing Room at KSC, POCC at MSFC, and Planetary mission controls at JPL) and planned future environments (e.g. SSCC and major onboard subsystems for SSF) are being built at all NASA Centers except LaRC and SSC. Total spending in these areas in FY 1990 will be approximately $10.5M.

Code MD runs the Advanced Operations Program which supports studies and protoype applications construction at JSC and KSC. The JSC work includes advanced graphics, simulation tools, and command processing languages for MCC, intelligent computer assisted training (ICAT), and autonomous methods for such applications as ascent guidance and onboard system management. The KSC work includes automated planning and scheduling tools, launch decision support systems, ICAT, operations analysis, and natural language interfaces. Total spending in these areas in FY 1990 will be approximately $4.5M.

Code MA (formerly Code ST, the SSF Strategic Plans and Programs Office) runs the SSF Advanced Development Program. About 75% of that program is relevant to the topics of this paper, including work in Flight Systems Automation; Ground Operations Automation; Space Station Information Systems; and Advanced Automation Software, Hardware, and Human Factors. Projects are underway at all NASA Centers except SSC, covering prototyping of applications of advanced technology to all major onboard subsystems (individual subsystems like power and thermal as well as subsystem coordination through OMS), ground-based systems like SSCC, and support systems like TMIS. Total spending in these areas in FY 1990 will be approximately $8M.

All three programs described above are frequent collaborators, co-funding certain activities and developing joint plans for technology transfer. One example of inter-program cooperation is the Real Time Data Systems (RTDS) series of expert systems applied to MCC at JSC. Early funding was provided to the Principal Investigator, John Muratore of JSC, by the OAST Artificial Intelligence Program. He developed the INCO Expert System through prototyping, flight testing, and routine use for STS missions. Expansion of the concept to other consoles was funded jointly by OAST and Code MD. Code MA

has added funding to apply the technology to the development of a Space Station Control Center (SSCC).

External to NASA, the governmental program of greatest relevance is that run by the Information Sciences Technology Office (ISTO) at DARPA. ISTO has funded basic research and military applications of IA, AOM, and CM since the late 1960's through a core technology program and the Strategic Computing Program. Of particular relevance to this paper is the Pilot's Associate element of Strategic Computing. Total spending of work related to this paper in FY 1990 is $30M. Through personal contacts and a MOU between DARPA/ISTO and ARC there is frequent co-funding and joint technology planning between ISTO and both the OAST Artificial Intelligence Program and Code MA's Advanced Development Program.

Key Contacts and Facilities

OAST AI Program	Mel Montemerlo	HQ-RC
	Peter Friedland	ARC-RIA
MD Advanced Operations Program	Chuck Holliman	HQ-MD
MA Advanced Development Program	Gregg Swietek	HQ-MA
ARC	Peter Friedland	ARC-RIA
	Monte Zweben	ARC-RIA
GSFC	Walt Truszkowski	GSFC-522.3
JPL	David Atkinson	JPL-366
	Richard Doyle	JPL-366
JSC	John Muratore	JSC-DF
	Troy Heindel	JSC-DC341
	Kathy Healey	JSC-EF5
	Bob Savely	JSC-FM721
KSC	Astrid Heard	KSC-PT-AST
LeRC	Karl Faymon	LeRC-5400
MSFC	Tom Dollman	MSFC-EB44
DARPA/ISTO	Steve Cross	DARPA/ISTO

Most of the work discussed in this paper takes place in existing Agency research and development facilities and is tested in existing (and planned future) operations facilities. A 1990 CofF has recently been approved to start construction of the Automation Sciences Research Facility at ARC which will contain office and laboratory space dedicated to advanced automation for all Agency missions. The most important resources are dedicated groups of scientists and engineers at a majority of Agency Centers, including world-class artificial intelligence research laboratories at ARC and JPL, and experienced artificial intelligence applications groups at GSFC, JSC, KSC, LeRC, and MSFC.

Major Issues and Needs

Several technical issues seem particularly important for improving operational efficiency of future mission control environments at NASA:

- **The correct mix of humans and machines for decision support:** taking into account costs, reliability, and capabilities

- **Integration of Artificial Intelligence and advanced interaction concepts (Hypermedia, Data Gloves, etc.):** mixing AI concepts that allow intelligent assistance with recently developed information presentation and manipulation methods

- **Hardware and software environments for realtime behavior:** developing computing environments that will allow effective use of advanced automation methods under the rigors of realtime Agency settings, both ground-based and onboard

- **Data storage and realtime access for very large-scale corporate memory systems:** supporting technology for information storage and management systems several orders-of-magnitude larger than those in common use today

- **Knowledge acqusition and maintenance during long-term missions:** how to make the corporate memory of a major Agency system (e.g. STS or SSF) a living entity that is continually updated and improved during a multi-decade lifetime.

It is the author's belief that the existing programs at NASA, primarily in OAST and Code M as described above, are well-positioned to meet current and future Space Transportation Systems needs in the areas of advanced mission control discussed in this paper. Either directly as civil servants or support service contractors at Agency Centers, or indirectly as grantees or contractors to those Centers, NASA has perhaps the best human resources in the nation in the three areas of **IA**, **AOM**, and **CM**. However several non-technical issues, relating to funding, organizational structures, and the current NASA culture (or at least how the culture is perceived) may seriously impact the progress of work in the area. Among those issues are:

- **How seriously does the Agency really take issues of life-cycle efficiency:** in the initial planning of major long-term missions (e.g. SSF) there is much talk of the need to consider life-cycle costs for maintenance, modification, and utilization. When the inevitable budget cuts arise, all funds which are not seen as essential for initial mission deployment are put in grave jeopardy.

- **Why is design discrete from operations:** current NASA organizational structures seem to segment system designers from actual and potential system users. A classic example is the Hubble Space Telescope. MSFC is responsible for getting it built, while GSFC is responsible for running it when it is built. This has led to rivalries as well as duplication of effort in designing automated operations systems for HST

- **Why is evolution discrete from operations:** current NASA organizational structures seem to segment those responsible for current systems operations from those responsible for the "next generation" of those operations. The JSC Mission Control Center is one such example where separate directorates are in charge of ongoing operations and design of the next operations environment. This, too, has led to rivalries and duplications of effort.

- **Does the current system of exhaustive verification and validation really lead to safer, more reliable mission control environments:** on the face of it it seems as though the more testing the better in potentially life and mission critical settings. However, in information critical environments (which all missions controls certainly are) it may be better to have more information sooner, even if some of it is clearly marked "incompletely verified" as long as human decision-makers are part of the control loop. Current structures impose huge time and cost burdens on making simple changes (perhaps based on results from prior missions) to mission control environments. Is that always right?

- **Is the current balance of research, development, and applications correct:** the current NASA environment seems to place enormous priority on those efforts which can show direct payback to ongoing missions in the very short term (at most a year or two). Our culture is to demand a precise schedule of "deliverables" for such work. For example, it is relatively easy to "sell" expert systems for ground-based information analysis and system diagnosis because the technology is "off-the-shelf" and construction of such systems can meet the same set of schedules expected for any software product. However, it is far more difficult to fund or provide precise schedules for longer-term topics that promise even greater impact on future mission controls; most of the work in the AOM and CM areas described in this report falls into that category. We tend to assume "somebody else" will do the fundamental work necessary to create new off-the-shelf technologies the way DARPA did for expert systems over the past twenty years. Is this the best strategy for an Agency whose devices and missions are among the most complex ever designed by humans?

None of the above issues are simple ones. In all cases the "correct" solution is most likely somewhere in the middle of two extremes. However, it is this author's perception that the current Agency culture is too close to one of the extremes and some changes may be in order. The final section of this document will make some recommendations.

Recommendations

The following recommendations are those of the author alone, although they do attempt to encapsulate many discussions before, during, and after the STATS meeting, particularly with John Muratore, Ray Hartenstein and Michael See of JSC, Tom Davis and Astrid Heard of KSC, Ann Blackburn of Mitre, and Ellen Ochoa and Monte Zweben of ARC. Recommendations will be given in three classes: technical, fiscal, and organizational.

Technical:

1. Continue the blend of technical topics being supported by the OAST, Code MA, and Code MD programs. Particularly encourage those that span several disciplines (e.g. artificial intelligence and human factors).

2. Begin a substantial Agency program (most likely in OAST) in the software engineering of large-scale, realtime systems that encompass both traditional and advanced automation methods.

3. Use the existing RTDS work at JSC to do a careful study to attempt to quantify increase in safety, reduction in manpower, and reduction and training time that will result from judicious use of automation in mission control environments. Almost all current work in this area is speculative, and an empirical study on the operational MCC systems would help in future decision-making.

4. Use SSF TMIS as a case study of CM systems for major Agency missions. Determine what capabilities will actually be provided and which would have been available with a 5-10 year research program prior to TMIS initiation.

Fiscal:

1. Ensure stable multi-year funding for scientific and engineering research and applications prototyping for the areas discussed in this paper. The funding should be at a fixed, small percent of operational funds (perhaps 5%), but should not be subject to elimination or serious reduction except on technical grounds of quality of work. There is no other way to ensure that life-cycle issues are not the first to be lost under inevitable short-term cost-cutting pressures.

2. Include careful analyses of life-cycle costs in all contractual selections of major space transportation subsystems. If the mission is designed to last 30 years, then selection should be made on total 30-year cost, not on initial cost of flight.

Organizational:

1. Do a better job of providing user partnership in design decisions. Whenever possible include users as part of design teams, SEB's, and the like in more than just a token fashion. Prototype major systems quickly and get user feedback from the prototypes instead of relying solely on lengthy, but often irrelevant, requirements documents.

2. Do a better job of connecting operational and "future-planning" organizations. Ideally, the latter should be part of the former, not a separate, often rival, organization. Personnel should flow freely between the two. The same comments about prototyping vs. requirements documents as discussed above apply.

3. Respect short, medium and long-term efforts equally within the NASA organizational culture. If a careful analysis of current missions and technology reveals a "hole" (such as the CM area) that will take many years of research to fill, then commit to supporting internal organizations for that necessary time. Recognize that different schedules and performance metrics apply to each class of activity.

4. Analyze and consider early testing, in operational environments, of prototype information management systems before exhaustive verification and validation. Consider safety and reliability of such systems in a larger context than simply ensuring against any possible harmful effects of that system. Particularly consider manual, semi-automatic (with human intermediaries), and fully automatic methods for providing incremental improvement in system operations during and between individual missions.

725

530663

16p

PRESENTATION 3.1.6

N91-17038

ADVANCED SOFTWARE INTEGRATION

October 25, 1989

Abstract - Space Transportation Avionics Technology Symposium
November 7-9, 1989
John R. Garman, Johnson Space Center

ADVANCED SOFTWARE INTEGRATION - THE CASE FOR ITV FACILITIES

Avionics software development has enjoyed an incredible evolution during the last 20 years. From Apollo, through Shuttle, and into the current plans for Space Station - the array of technologies and methodologies involved in the development and integration of avionics software has moved almost as rapidly as computer technology itself.

Future, near future, avionics systems involve major advances and risks in the following areas:

a) Complexity
(technology, functionality)
b) Connectivity
(distributed, networks, remote resources)
c) Security
(privacy, protection, integrity in development and maintenance)
d) Duration
(" never ending" and evolutionary)
e) Software Engineering
(layers, encapsulation, objects, etc.)

From an architectural point of view, the systems will be much more distributed (including flight/ground), involve "session"-based user interfaces, and have the layered architectures typified in the "layers of abstraction" concepts popular in networking (e.g. OSI) and software engineering design standards today.

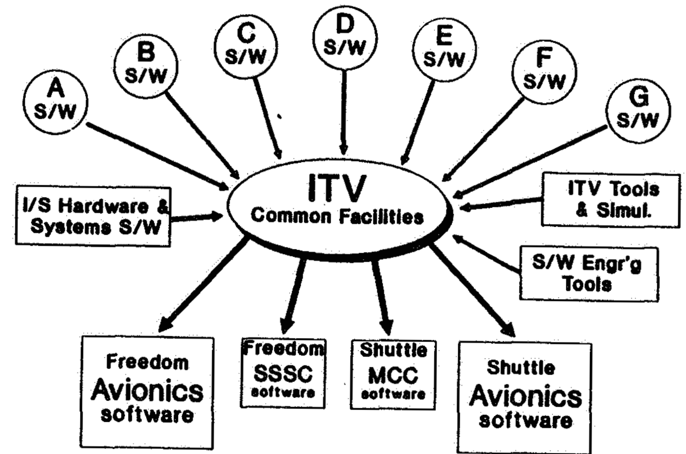
Perhaps most important, and typified in the NASA Space Station Freedom program, will be the highly distributed nature of software development itself. Whether it be the integration of "off-the-shelf" or reusable products, or the integration of components separately developed by teams of contractors and subcontractors distributed to remote locations, it is the "decentralization" of software development itself that probably contributes the most fundamental changes in avionics software management and integration in the 90's.

Systems composed of independent components developed in parallel must be bound by rigid standards and interfaces, the clean requirements and specifications. Nonetheless, it is the integration of the separate components into whole which provides the real challenge. Avionics software provides a compounding challenge in that it can not be "flight tested" until the first time it literally flies. This normally means that man-rated or safety critical avionics software must obtain that rating and certification in simulated environments of the real systems and vehicles. It is this combination of verification in a "virtual" target environment coupled with the distributed nature of the component development, which led to special ITV (Integration, Test, and Verification) concepts for the Shuttle, and now Space Station Freedom Programs. The latter employs a "Multi-System Integration Facility" concept for its avionics and ground mission systems. While the name and scope has and will evolve, the underlying concepts, vis a vis software integration remain the same.

It is the binding of requirements for such an integration environment into the advances and risks of future avionics systems themselves, enumerated above, that form the basis of this paper and the basic ITV concept within the "never-ending" development and integration life cycle of Space Station Mission and Avionics systems.

Advanced Software Integration

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
ADVANCED SOFTWARE INTEGRATION



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Major Objectives

- Maintaining reliability in increasingly complex software and information systems (contrasts in STS and SSFP avionics).
- Enabling evolution (functionality, technology, connectiveness) in systems which are now "never-ending".
- Managing increasingly distributed work-packets and efforts in the development of applications software for the advanced systems.
- Reuse and commonality (across systems and programs) both an operations efficiency (training, management, etc.) and as a productivity item.

stats02-jrg1031

Key Contacts & Facilities

Contacts:
- John R. Garman/JSC(FA)
- Ed Chevers/JSC(FR)
- Rick Coblentz/JSC(FR)
- Jack Seyl/JSC(FS)
- Charles McKay/UHCL (JSC)

Facilities:
- Information Systems Technology Lab (ISTL)/JSC(FA)
- Avionics Development Lab (SSFP/WP2)/JSC(FR)
- Software Development Facility (NSTS)/JSC(FR)
- Support Software Environment Development Facility (SSEDF)/JSC(FR)
- Mission Systems ITV Facility/JSC(FS)

Major Milestones (1990-1995)

- Operation of STS SAIL and SPF (1976)
- SSE Baseline for SSFP (1990)
- Avionics Integration and ITV baseline for SSFP (1990)
- Mission Systems ITV (MSITV) Facility Design (1990)
- ADF and MSITV FOC (1992)
- Shuttle and SSFP ITV commonality (1997)

Advanced Software Integration (cont'd)

Technology Issues

- **Containment of growing drivers: complexity, connectivity, security, and architectures**
- **Standardization of I/S "layers" - industry standards**
- **Virtual target environments (exact simulation of target platform allowing diagnostics)**
- **"Project Object Database" - the database and management technologies involved in creating a single unambiguous image of the entire distributed software system**
- **Integration of heterogenous products designed against common standards (both the host and target domains)**
- **Software Lifecycles modeled against evolutionary development and maintenance (vs. waterfall)**

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Candidate Programs

- NSTS Avionics Flight Software
- NSTS Mission Control Center Upgrade
- NSTS Other I/S
- SSFP Data Management System (avionics)
- SSFP Mission Control and Trainers
- SSFP Other I/S
- Advanced Programs (Lunar/Mars)

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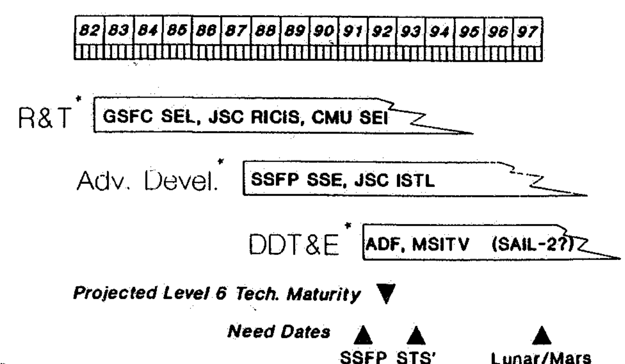
Major Accomplishments/"Inabilities"

✓ Major Accomplishments
- Establishment of RICIS
- Establishment of SSE development effort
- Baselining of commonality in applications tools and UI for SSFP
- Industry evolution toward standardization of I/S layers

✓ Major "Inabilities"
- Duplication of effort across Programs/Projects
- Proliferation of mission supporting software
- Inability to fully utilize COTS
- Inability to upgrade existing capabilities

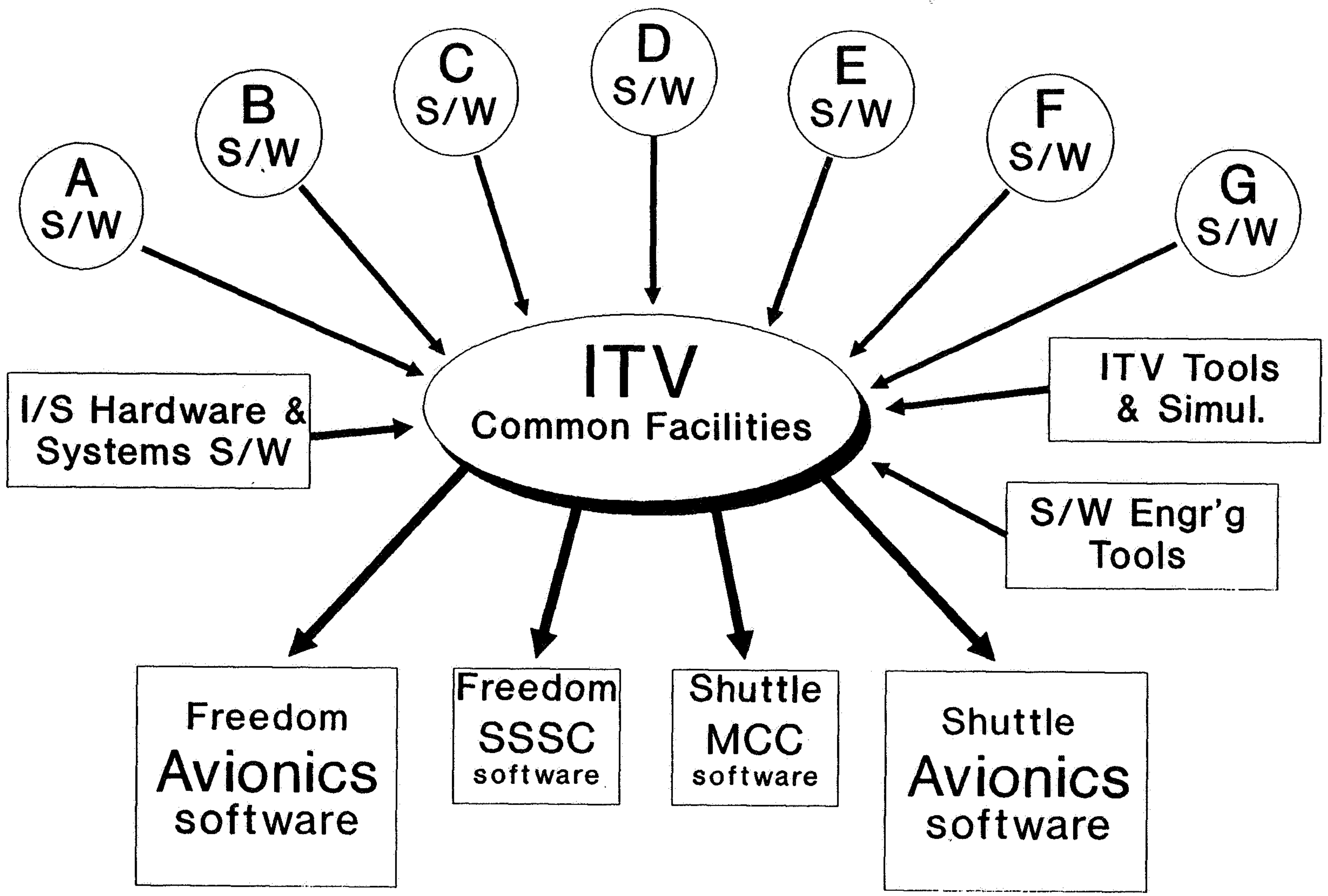
SIGNIFICANT MILESTONES
Advanced Software Integration



*(Technology Phases)

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM

ADVANCED SOFTWARE INTEGRATION



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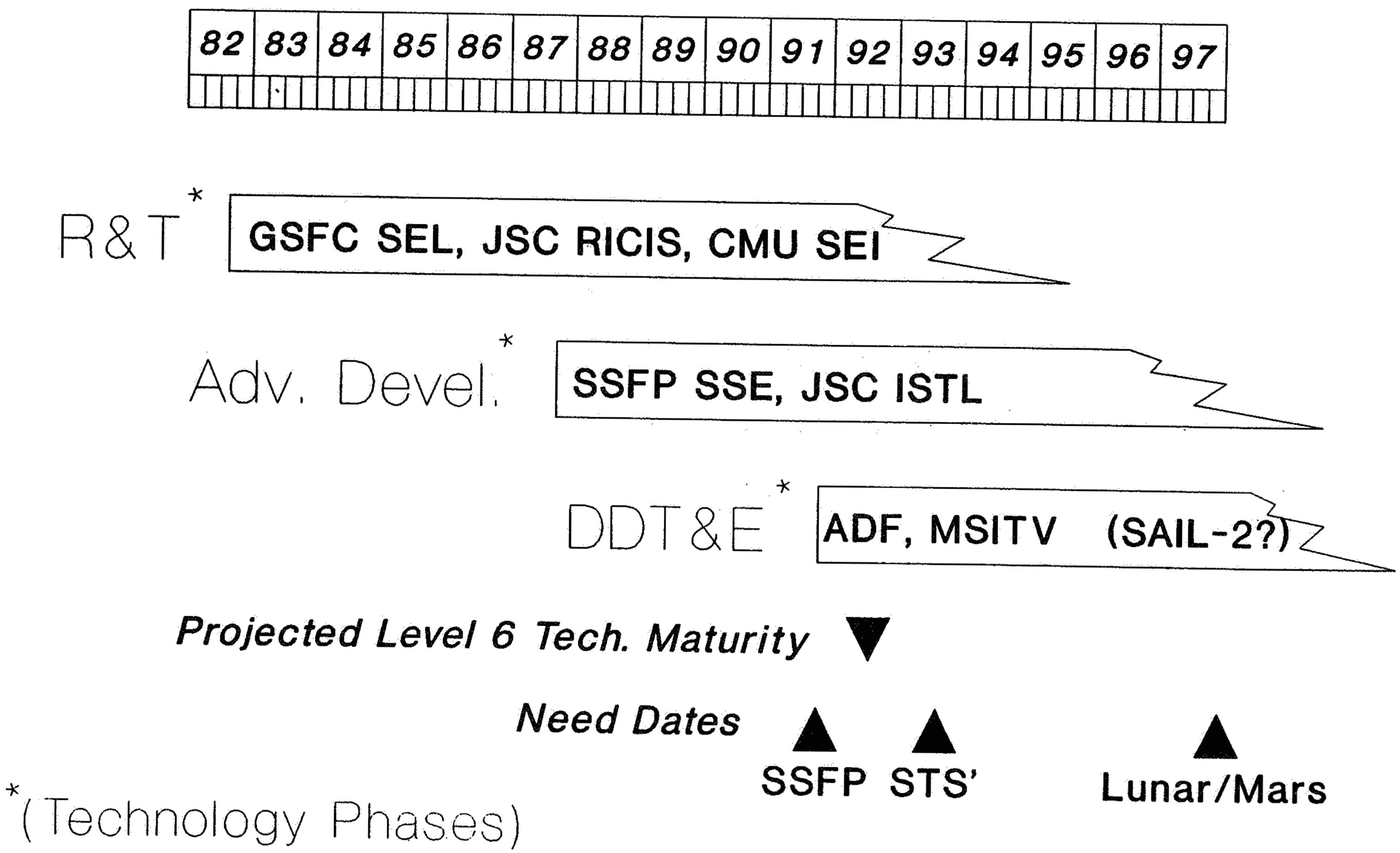
Advanced Software Integration



FLIGHT ELEMENTS PANEL

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PRESENTATION 3.2.1

N91-17039

ADVANCE AVIONICS SYSTEM ARCHITECTURES

SPACE TRANSPORTATION AVIONICS SYMPOSIUM
FLIGHT ELEMENTS

ADVANCED AVIONICS SYSTEMS ARCHITECTURES

SCOPE

The idea that an avionics system has, or should have, an architecture is a notion that has come about slowly over the past twenty years. Avionic systems began as individual controllers typically associated with individual vehicle subsystems. As the controllers became based on digital technology, opportunities for information exchange between subsystems increased because digital data bus technology permitted the information to be exchanged without the degradation associated with analog signal transmission. Vehicle subsystems became integrated by sharing information to improve vehicle performance or to avoid the expense and weight of duplicated information sources. The flexibility of digital information sharing provided additional opportunities for changing systems once they were constructed since all that was required in many cases were software changes. The rush to interconnect digital systems has been somewhat of a mixed benefit since system complexity grows as at least a power of the number of connections and perhaps exponentially. Even the accounting task of tracking information sources and users can become formidable. A result has traditionally been that the supposedly "free" information exchange resource becomes choked trying to accommodate the transmission requirements imposed after the system has been constructed. All too often systems are designed using the best engineering judgement and then bludgeoned into submission on the laboratory floor. There is the question of organizational responsibility when subsystems that have been the responsibility of separate organizations become interdependent. For example, it is feasible to use the high-quality rate information from inertial platforms, historically a navigation function, to stabilize the vehicle, a control function with much higher reliability requirement. Which organization controls the platform? There are many such new questions that come about as traditional boundaries between subsystems break down and the vehicle itself becomes the boundary. It is not now feasible to address all questions that can be raised as a result of attempting to design integrated system architectures. An appropriate limitation of the scope of this topic is to consider the avionic flight system as the substrate upon which the applications are built, and as such, must support airborne, and one-time ground functions such as guidance and control, health monitoring, ground maintenance diagnostics, etc. If a sufficiently good understanding of the capabilities and limitations of a useful class of architectures and their requirements can be obtained such that it is feasible to make sound engineering decisions before fabrication, that would be a reasonable and useful

goal. The study of digital avionics system architectures is just being accepted as a separate topic. Fault-tolerance is an aspect of systems architecture that, while it may appear to be a cure-all for system failure, has many subtleties that limit its effectiveness. Some important concepts have been identified such as system synchronization and protection against inconsistent data distribution, but a general theoretical framework for system architectures is a future goal.

OBJECTIVES

Space transportation objectives are associated with transporting materiel from Earth to orbit, interplanetary travel and planetary landing. The objectives considered here are associated primarily with Earth to orbit transportation. Many good avionics architectural features will support all phases of space transportation, but interplanetary transportation poses significantly different problems such as long mission times with high-reliability, unattended operation, and significantly different opportunities such as long non-operational flight segments that can be used for equipment fault diagnosis and repair. Although it is not further considered in this write-up, the maintenance of system operation for long mission times is a "hole" in current research since fault-tolerance does no good if the underlying physical devices do not exhibit some minimal reliability for the entire mission. With the trend toward smaller geometries and new physical technologies, it is quite likely that heretofore unimportant failure modes will become dominant over long mission times. Avionic systems that are used in the Earth to orbit scenario can be years in production and months in assembly and checkout on the launch pad. The system life culminates in a ten minute operation with some factors such as acceleration, vibration and temperature dramatically different from anything previously encountered other than during system qualification in the qualification laboratory. The launches tend to be infrequent and very expensive with very expensive payloads. They involve hundreds of launch site personnel servicing a vehicle, using complex scheduling to allow each subsystem expert time in the very limited area around the vehicle. When the vehicle is ready, the launch is subject to the vagaries of the weather and to the pressures of fixed launch windows. Avionics systems for launch vehicles should be designed and fabricated to support worthwhile goals such as low recurring hardware and operations cost, launch on demand, flexible and secure interfaces for payloads and other integrated non-avionics systems, and be open ended to grow and change within the relatively long service life of launch vehicles. Some specific objectives for launch vehicle architectures should be selected to achieve improved reliability at lower cost. Fault-tolerance can be used to permit continued operation with faulty units, not only during launch but also, and perhaps with more impact, during pre-launch activities. Completing subsystem tests without stand-down for avionic systems repair can save facility and personnel time that is much more expensive than the electronics. This will be

especially beneficial because, except for the factors noted above, the avionic system operates at rated performance during system checkout, which may take weeks, and may even support factory assembly and health monitoring for months. Ground operations can be stressful in ways different from the launch. For example, ground temperature stress can vary greatly and be sustained for much longer than flight stress. Also, work on other systems can inadvertently stress the avionics and vice versa. Launching the vehicle with faults is problematical since the idea of committing an expensive vehicle to launch with an inexpensive part failed will require a cultural change within the launch vehicle community. If acceptable criteria can be established, vehicle life-cycle costs can be lowered by permitting launch with faults. Another beneficial specific objective is to design avionics subsystems to go from factory to flight without calibration or other adjustments. Suitable internal diagnostics and criteria must be provided to permit satisfactory operation to be confirmed by launch site personnel and to allow ease of fault isolation, change-out and retest in case of failure. As principles of system architecture design become established through research, these should be applied to all avionic systems across the entire vehicle from sensor to effector to provide a uniform basis for measuring avionic system performance through such features as common interfaces and subsystem redundancy management procedures. The specific physical technologies may be different for different functions, for example the engine controller may require high temperature electronics, but the underlying elements for functions such as synchronization and redundancy management could be uniform over the entire avionic system. Diagnostic routines and architecture modeling would then provide detailed insight into avionic system health. Since the avionic systems are becoming more capable and are not the time or cost drivers for checkout, they will have to aid the diagnostics and integration for other subsystems. An important objective in this case will be to establish the avionic system capability to accommodate perhaps thousands of measurements and hundreds of control functions. This implies a large quantity of data, even if individual measurement is taken at a low data rate. On-demand subsystem health data has been suggested as a means to gather data from subsystems when significant changes occur, thus reducing the background data rate to a low level. This approach may be beneficial when subsystem events occur at random, but a global event such as a lightning upset could cause many subsystems to try to report the event simultaneously causing data overload.

SIGNIFICANT RESEARCH ACTIVITIES

The most significant recent research activity targeted at launch vehicle avionics has been the Advanced Launch System (ALS) Advanced Development program. The Advanced Launch System is conceived to be a series of medium to large

launch vehicles with the common characteristic that the cost of placing a pound of payload in orbit will be roughly an order of magnitude less than the Titan IV reference-mission cost. In order to meet this goal, it is proposed to utilize advanced, fault-tolerant avionics to support concepts such as knowledge-based system diagnostics for autonomous pre-launch checkout and advanced guidance and control to permit launches in a wider variety of weather conditions than are now possible. The ALS program has, under the title of Multi-path Redundant Avionic Systems (MPRAS) leveraged on-going research efforts at both NASA and Air Force laboratories to develop the required launch vehicle systems. One such effort is being conducted at The Charles Stark Draper Laboratory (CSDL) as the NASA-sponsored Advanced Information Processing System (AIPS). The AIPS program is developing technology that will apply to a wide variety of system needs. It embodies the latest concepts for achieving fault tolerance, graded to be appropriate to the individual function being performed and is designed to be validated to the required reliability and performance. The AIPS concept is illustrated in figure 1 and embodies the advanced architectural concepts that will be covered in the section on technology issues. Another MPRAS effort is being conducted at Boeing Aerospace and is leveraging the Integrated Fault-Tolerant Avionic System (IFTAS, figure 2) to provide capabilities similar to those of the AIPS. A third MPRAS effort is underway at General Dynamics Space Systems, leveraged from Air Force Pave Pillar avionics concepts as illustrated in figure 3. Martin Marietta is developing a large laboratory with a focus on developing reliable, fault-tolerant systems for launch vehicles. The Space Station Freedom data management system architecture illustrated in figure 4 shows a point design with many fault-tolerance features. A significant source of fault-tolerant avionics experience can be found in aircraft systems. Aircraft systems have not labored under the extreme weight sensitivity and reluctance to technological change of most launch vehicle avionics systems (Shuttle is one exception), so that redundancy has for many years been an accepted way to accommodate aircraft system faults. Both in civilian and military aircraft systems, redundant, fault-tolerant avionics have been successfully used in the operational environment of scheduled arrivals and departures to which the space transportation community aspires. The consequences of aircraft avionics system failure are typically not catastrophic, although both commercial and military systems are close to being used for full-time, flight-critical functions where system failure would have the same catastrophic impact as a launch vehicle system failure. All of the major U.S. airframe manufacturers have, in partnership with avionics manufacturers, fielded fault-tolerant avionic systems for high reliability applications, most notably for autoland where the autoland function is critical for up to a minute of flight just prior to touchdown. Fault-tolerance for single function applications appears reasonably well accepted, but the aircraft systems designers are still wrestling with the problem of designing vehicle-wide avionic systems that are manageable and exhibit sufficiently long time between maintenance. Advanced vehicle-wide

architectures for military applications are being pursued at Wright Research and Development Center under the Pave Pillar and Pave Pace programs which feature very high performance architectural elements to support various fault tolerance strategies and which are being rendered into hardware using a common module approach to promote lower production and maintenance costs. Honeywell has for a number of years been developing the concept of self-checking pairs to achieve high fault detection coverage for processors, buses and the checkers themselves. This concept is illustrated in figure 5. Self checking pairs is one of the main features MPRAS has defined to enhance Pave Pillar designs. There has been recently renewed interest in protection of avionic hardware from electromagnetic disturbances from natural causes such as lightning or man made high energy radio frequency emissions. This aspect of avionic system design is being most visibly pursued by Honeywell although it is a recognized problem within the aerospace industry. Launch vehicle launch-on-demand capabilities are somewhat dependent on lightning hardness to minimize the need to avoid lightning strikes during ascent. Transients from other, less well defined sources can cause faults in the form of single event upsets that, although they cause no permanent damage, can alter the performance of avionic systems in harmful ways. In addition to these efforts many universities have significant results that can be incorporated into the design and testing of fault-tolerant avionic systems. Table 1 is a list of organizations known to have significant efforts in fault tolerant avionic systems. Most aerospace companies now have more than a passing interest in fault tolerant systems since their use has become pervasive in flight vehicles. Table 2 lists some of the more prominent periodical publications and conferences where technical discussions of advanced avionics are to be found.

TECHNOLOGY ISSUES

Avionic system architecture impacts and is impacted by virtually everything within the vehicle since the digital systems are increasingly used to integrate the activities of vehicle subsystems to achieve performance unattainable with more traditional engineering approaches. The capability of digital avionics, with logic unfettered by the laws of physics, to direct otherwise mundane systems to perform brilliantly in concert is a powerful reason to employ such systems. Unfortunately, the same logic that can correctly find the few ways to make things go right can also make things go wrong in an almost infinite number of ways. The unimaginable complexity of digital systems cannot in general be managed by appeals to physical properties since they are designed out of practical consideration by the nature of the digital logic. Correct design of digital systems is a technology issue that becomes increasingly difficult to manage with the trend toward distributed, fault-tolerant systems. Since most fault-tolerant architectures use replicated, identical elements to protect against random physical failures, a design flaw becomes a generic failure for the entire system. The systems can be

modeled as an aid to understanding but testing alone cannot be used for system validation because of the large state spaces that must be tested. Fault-tolerance brings with it the possibility of reducing the failure probability of avionics systems to a negligible amount. However, once the more prominent failure modes have been covered using fault-tolerance, other failure modes become important and they are generally much more subtle and hard to identify, much less quantify. The reliability of the fault-tolerant system becomes almost totally dependent on the fault-tolerance mechanism. This is especially true of reconfigurable fault-tolerant systems since the reconfiguration mechanism can disable good units in response to unexpected inputs or its own internal faults. Therefore, design correctness and a comprehensive accounting of all possible inputs and actions are of paramount importance.

As the digital processing and bus capability keep expanding, and volume per MIPS shrinks, the feasibility and benefit of more integrated non-avionic systems has also increased. The mix of computation and input/output is changing such that I/O accounts for an estimated 75 percent of the avionic system and an even greater portion of system unreliability and cost, because the I/O must service a variety of subsystems and cannot be made as uniform and modular as the computation system. The technology to support effective and efficient input/output design and validation is a new and different area for the avionic systems technologist.

Software development for avionics systems is a critical issue because of the special need for correctness of the system software. There is much less opportunity to check the correctness of system software because the totally logical aspects of digital systems typically have fewer independent correctness criteria to check against. There is also less time to do checking because the system software must be executed more often than application software. Software development environments and languages must be tailored to support system as well as application development. Architectures that are based on combinations of a small number of well understood building blocks offer a means to limit complexity, but the utility of such approaches has yet to be demonstrated. Space systems traditionally use single string systems with individual components qualified to the highest levels. Whether a less costly system of higher reliability can be assembled using lower reliability parts is an issue currently under examination both from technological and cultural standpoints. Aircraft systems used in commercial or military operational situations can be dispatched with a given number of faults, and this is a key to practical systems utilization since it is exceedingly difficult to achieve a perfect operational state, especially where the systems must be serviced and maintained by personnel who are not experts dedicated to particular hardware items. Hardening avionic systems against external electromagnetic disturbances and random transients is a difficult

problem since the electromagnetic threats and random transients have not been completely characterized for all threat sources. The effects of transients and electromagnetic disturbances on digital systems are difficult to characterize since they are less well contained than the isolated one-at-a-time faults that traditional fault-tolerance schemes protect against.

SUMMARY

Avionics systems are entering a phase of development where the traditional approaches to satisfactory systems based on engineering judgement and thorough testing will alone no longer be adequate to assure that the required system performance can be obtained. A deeper understanding will be required to make the effects of obscure design decisions clear at a level where their impact can be properly judged. This deeper understanding will be provided by tools and techniques that are just now being developed in research laboratories. Digital avionics systems will increasingly be the means by which many of the U.S. space goals will be accomplished. Now is an opportune time for the space vehicle community to step up to placing advanced, fault-tolerant avionic systems into general use by building on the experience of the aircraft industry supplemented by a fresh look at the tools and techniques for designing, fabricating and testing complex avionics systems.

Table 1
Organizations and Contacts

Organization	Contact
NASA Langley Research Center	Charles Meissner Felix Pitts
NASA Johnson Spaceflight Center	Tom Barry J. T. Edge
C. S. Draper Laboratory	Jay Lala John Deyst
Honeywell Systems Research Center	Mark Jeppson
Honeywell Commercial Flight Systems	Richard Hess Larry Yount
General Dynamics Space Systems	John Karas

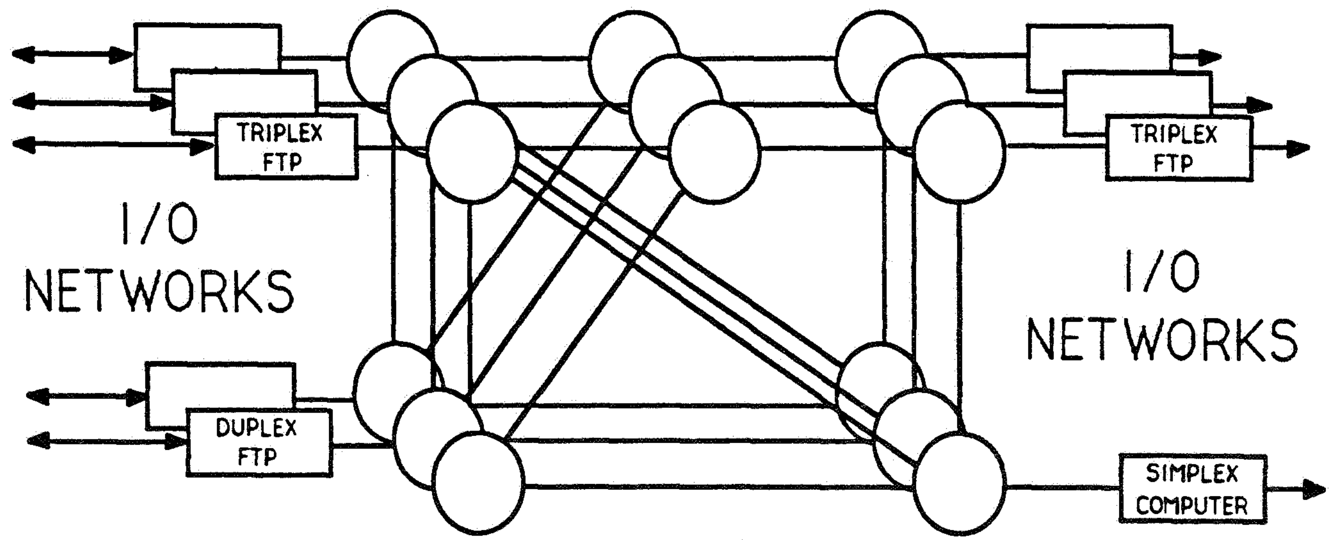
Table 1 (concluded)

Martin Marietta Astronautics Group	Robert Gates
Boeing Aerospace	Don Johnson
Lockheed/Sanders	Raymond Garbos
Wright Research and Dev. Center	Ron Szkody Raymond Bortner Jeff Stanley
Jet Propulsion Laboratory	David Rennels
Aerospace Corporation	George Gilley
Allied Signal ATC	Chris Walter
UCLA	Algirdas Avizienis
Fail Safe Technology	Mike Seavers

Table 2
conferences and Periodicals

Conference/Periodical	Sponsor
Digital Avionics System Conference	IEEE AIAA
Computers in Aerospace Conference	AIAA IEEE
Fault Tolerant Computing Symposium	IEEE
Reliability and Maintainability symposium	IEEE
National Aerospace Electronics Conference	IEEE
IEEE Transactions on Reliability	IEEE

Advanced Information Processing System



Features: **ADA Operating System**
Fault-Tolerant Distributed Processing Sites
Fault-Tolerant Inter-computer Network
Appropriate Function Reliability
Low Fault Tolerance Overhead
Growth Capability
Redundancy Transparent to User

Figure 1 - Advanced Information Processing System (AIPS)

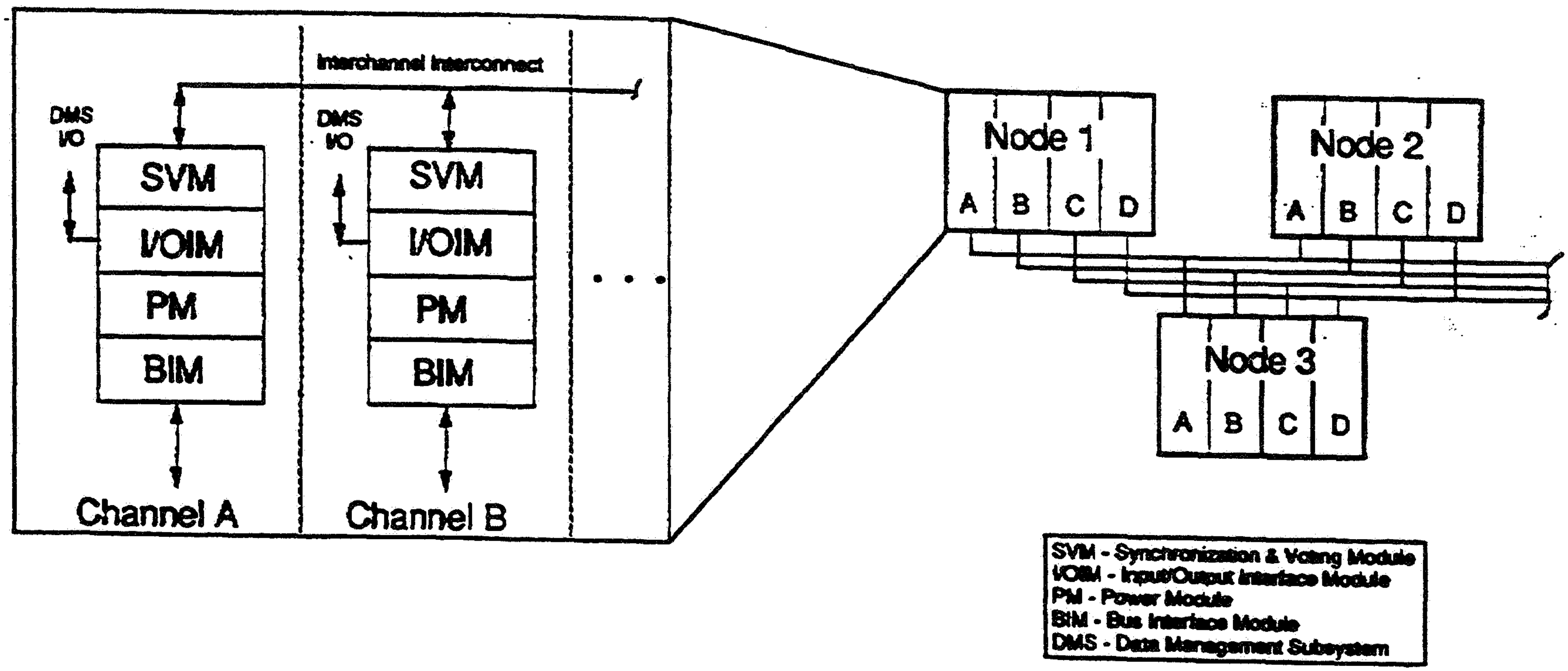


Figure 2. IFTAS
Hybrid NMR Block Diagram

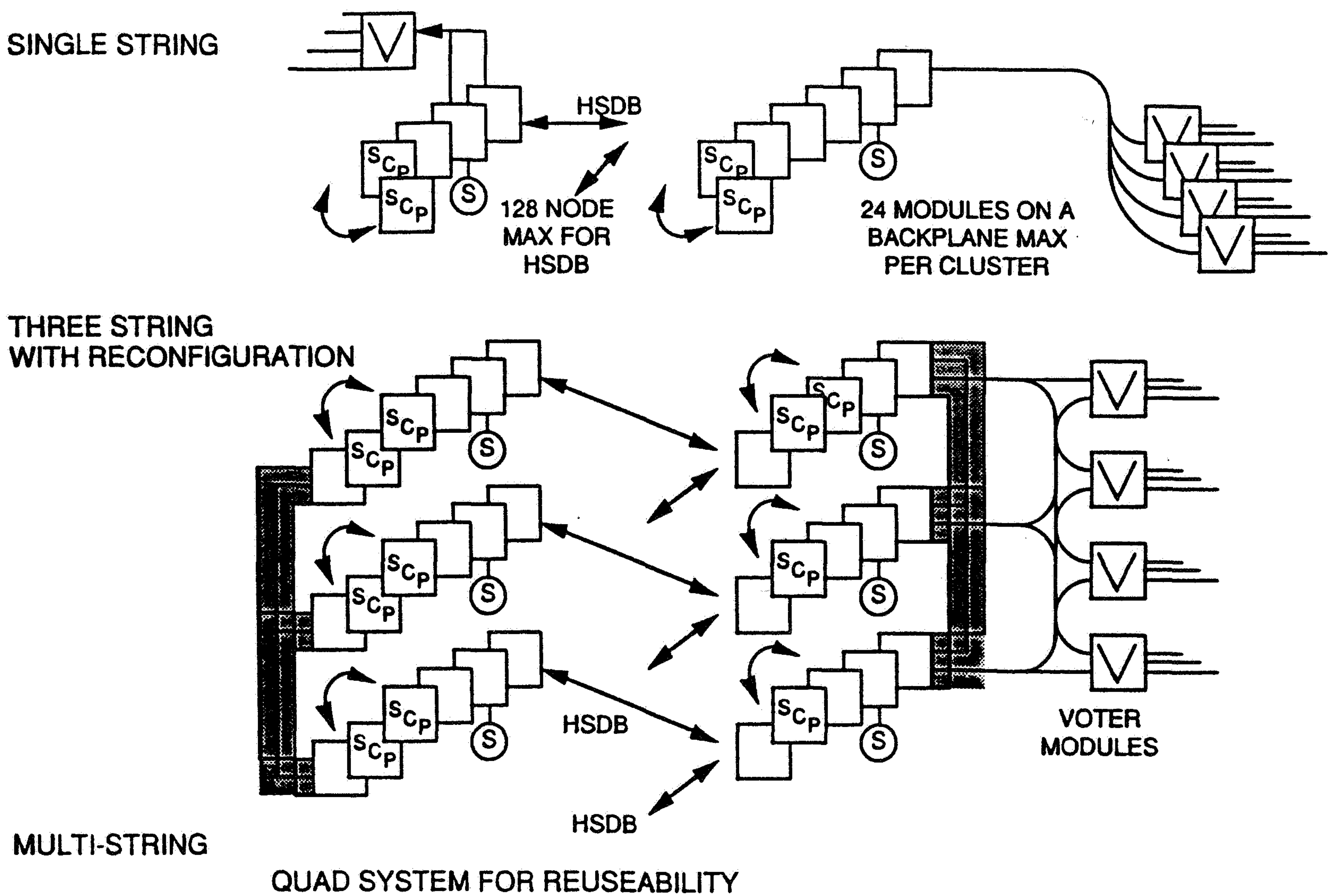


Figure 3. MPRAS Architecture Configurations

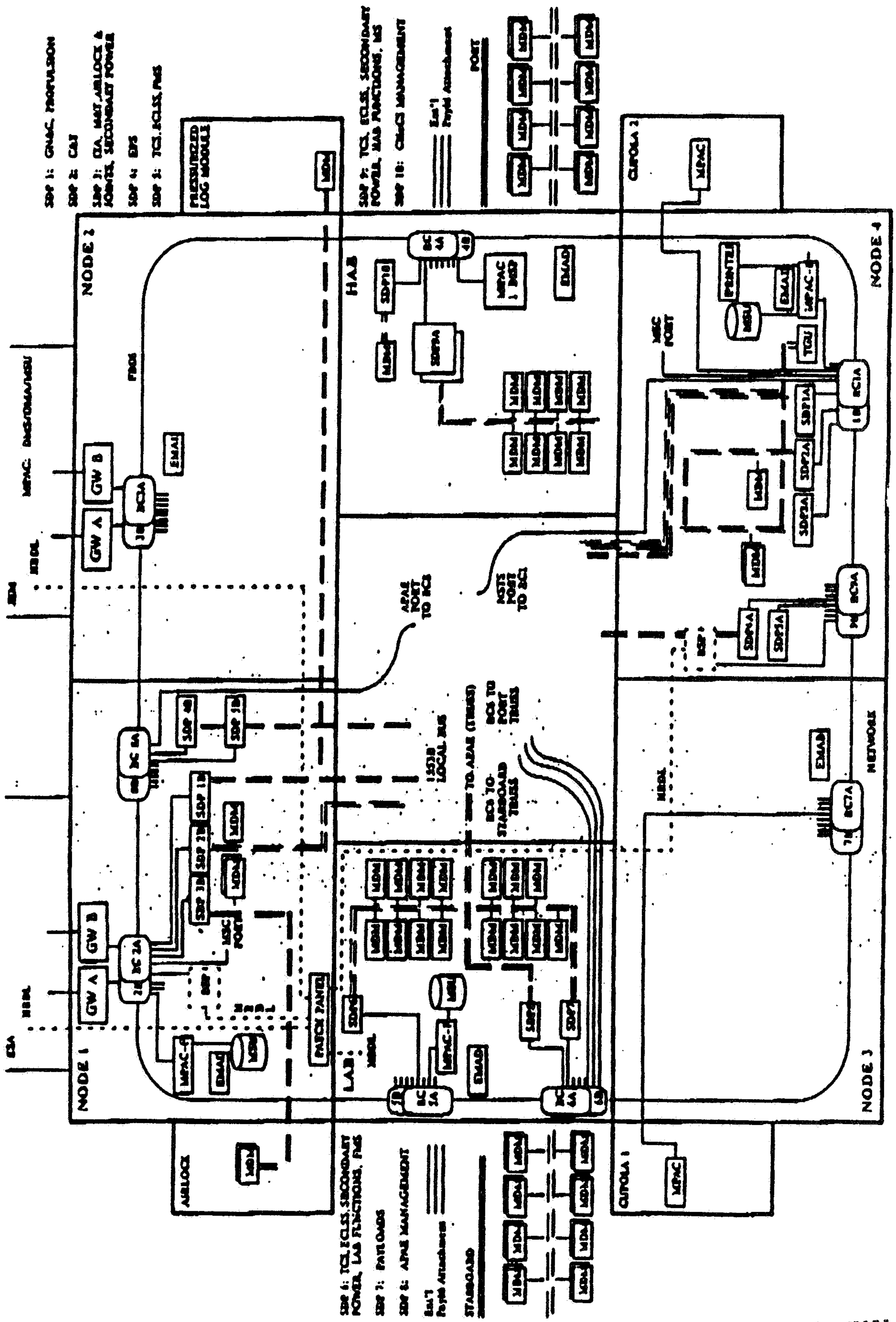


Figure 4. Space Station Freedom DMS Overview Schematic

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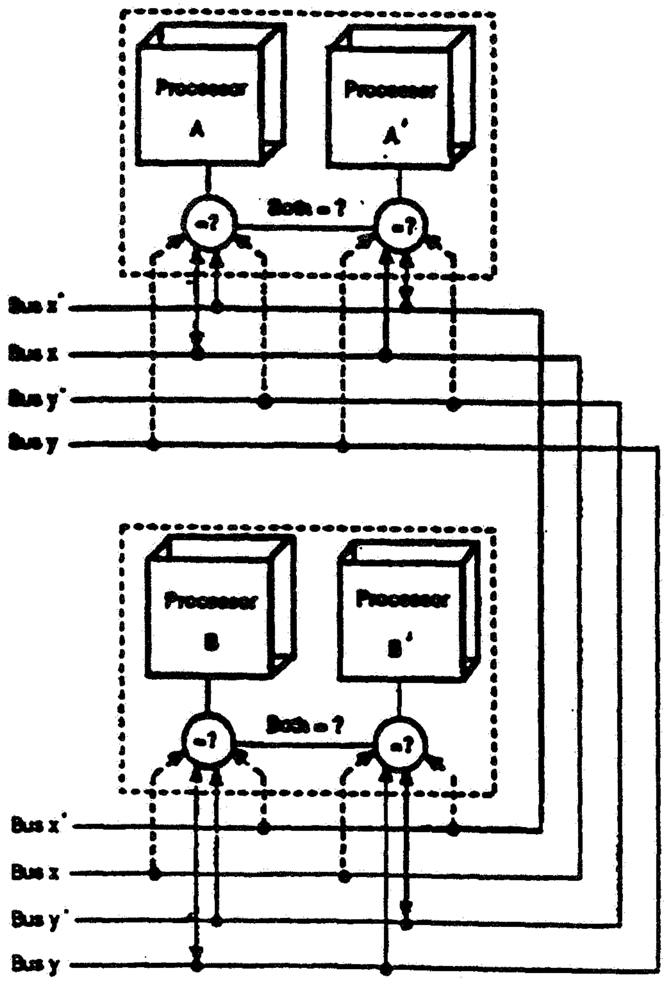
Atomic Self-Checking Pairs

Honeywell



- **Characteristics**
  - Processors, Busses and Checkers are paired
  - Pairs are atomic (indivisible)
  - Each pair forms a fault containment zone
  - Halves of a pair are synchronous
- **Fault Detection**

  Near unity coverage, even the checkers are self-checking pairs
- **Fault Isolation**

  Unambiguous because of atomic property and has solution to the Byzantine Grenerals Problem
- **Fault Recovery**

  Fully distributed scheme means there is no mechanism that can become a single point of failure

KD>TBC/0587/DS-9

Figure 5. Atomic Self-Checking Pairs

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ADVANCE DISPLAYS AND CONTROLS

AN ASSESSMENT OF ADVANCED DISPLAYS AND CONTROLS TECHNOLOGY APPLICABLE TO FUTURE SPACE TRANSPORTATION SYSTEMS

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Hampton, Virginia 23665

and

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AN ASSESSMENT OF ADVANCED DISPLAYS AND CONTROLS TECHNOLOGY APPLICABLE TO FUTURE SPACE TRANSPORTATION SYSTEMS

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INTRODUCTION

This paper addresses the topic of advanced display and control (D&C) technology, covering the major objectives of this technology, the current state-of-the-art, major accomplishments, research programs and facilities, future trends, technology issues, space transportation systems applications and projected technology readiness for these applications. It will also address the holes that may exist between the technology needs of the transportation systems versus the research that is currently under way, and will recommend cultural changes that might facilitate the incorporation of these advanced technologies into future space transportation systems.

OBJECTIVES

Some of the objectives of advanced D&C are synonymous with those of most other advanced avionics technology concepts for space transportation systems. These include reduced life cycle cost, improved reliability and fault tolerance, use of standards for the incorporation of advancing technology, and, of course, reduced weight, volume, and power. Additional objectives of advanced D&C are to reduce the pilot's workload and improve the pilot's situational awareness, resulting in improved flight safety and operating efficiency. This will partially be accomplished through the use of integrated, electronic pictorial displays, consolidated controls, artificial intelligence and human-centered automation tools. Another objective is to reduce or eliminate paper/manual clutter, such as the Shuttle flight data file, through the use of interactive optical disk technology. The proposed Orbiter Glass Cockpit Display Upgrade Program is an example of a system which attempts to implement some of these objectives. This program will be discussed in a later paragraph.

CURRENT STATE-OF-THE-ART

The current state-of the-art, as well as a potential future direction, in advanced D&C technology is indicated in Figure 1. Representing the state of current D&C technology is

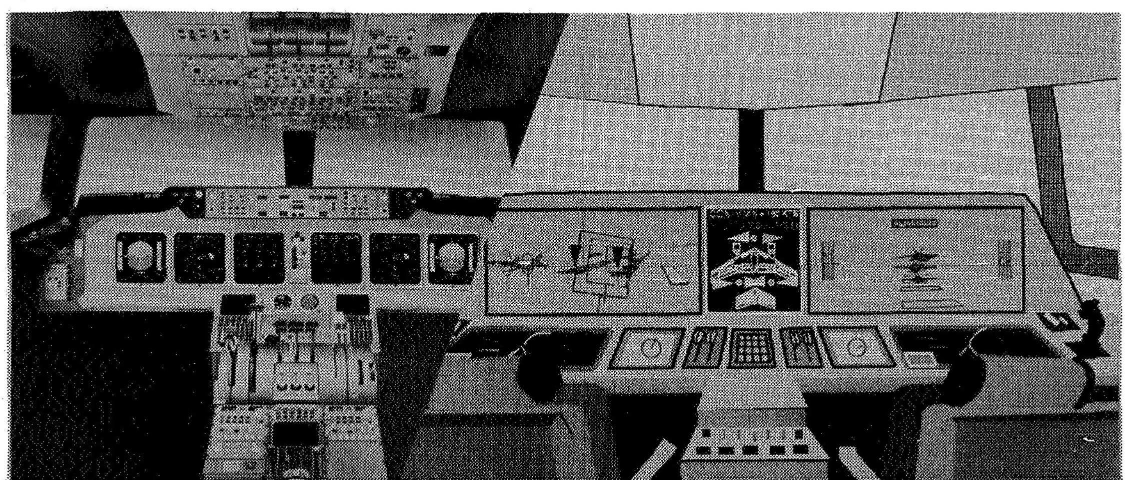

Figure 1.- State-of-the-art transport cockpit (MD 11) and a vision for future cockpits.

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the McDonnell Douglas MD11 transport aircraft cockpit. Here, a clean, uncluttered pilot interface is provided by an "all-glass" cockpit configuration. Display information is computer-generated on full-color cathode ray tube (CRT) displays. The displays are six side-by-side form-factor "D" units, having a 6.25" x 6.25" display surface. Even though the displays are electronic, the format of the presentations are largely renditions of earlier electromechanical displays, such as those presently used in the Space Shuttle. Flight control and engine status information is presented on the two outside primary flight displays (PFD's) and the two inside engine-monitoring/systems status displays. Navigational information, in the form of navigational charts (maps) or horizontal situation indicators (compass rose), is presented on the two inside displays that are between the PFD's and the two center displays. Pilots interface with the aircraft control system and the navigational system primarily via the glare-shield control panel and the navigation control/display units (keyboard/ display units shown in the center console). The MD 11 employs extensive use of reliable digital avionics and automation to aid the pilots in flight management, aircraft control, and on-board systems monitoring.

A vision for the future cockpit is shown also by Figure 1, an advanced cockpit technology concept emanating from the aero human factors R&T base program at Langley Research Center (LaRC). Depicted here is an advanced, "all-glass" flight deck which is unusually clean and uncluttered and which makes use of large-screen, integrated, pictorial display technology and human-centered automation. This concept and the technology which it embodies will be discussed in a paragraph below.

A major thrust that is underway in the research and development community is the replacement of the color CRT display technology with flat-panel display technology. The main thrust of these flat panel display devices is to minimize depth, weight, and power consumption, as well as to improve reliability and sunlight view-ability. The potential advantages of flat-panel technology vs. CRT technology are presented in Figure 2.

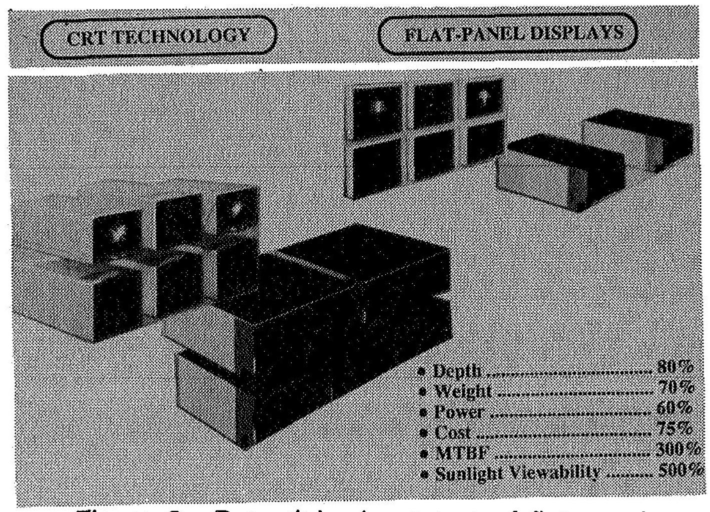

Figure 2-. Potential advantages of flat-panel display technology over the CRT.

Currently, the most promising full-color flat-panel technology is the Active-Matrix Liquid Crystal Display (LCD). One such device, made by General Electric, is currently undergoing bench testing in the Advanced Systems Development Laboratory at Johnson Space Center (JSC). It has a 6.25" x 6.25" usable screen area, and is capable of high-resolution (1024 X 1024 picture elements) graphics and/or video with 16 gray scale levels. An example of a this display is shown in Figure 3, which illustrates a typical primary flight display (PFD) format.

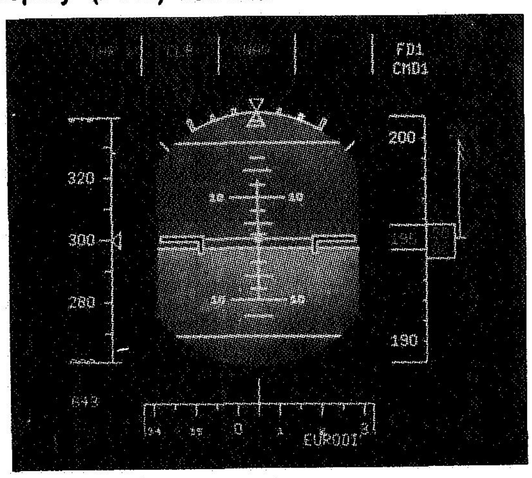

Figure 3.- State-of-the-art color LCD.

Such a device is typical of what might be installed in Shuttle, as part of the proposed Orbiter Glass Cockpit Upgrade Program, to achieve the advantages indicated by Figure 2.

MAJOR ACCOMPLISHMENTS

Some of the major accomplishments which have occurred in the area of advanced D&C during this decade will be discussed next.

The most notable accomplishment is the emergence of several glass cockpits in commercial and military aircraft such as the Boeing 747-400, the Gulfstream G IV, and the McDonnell Douglas MD11. In these cockpits, the conventional electromechanical flight instruments have been replaced with color CRT's driven by modern processors. Since the displays and processors are on a bus, the system can be readily reconfigured in the event of hardware failures. Additionally, these cockpits have made extensive use of built-in-test-equipment (BITE) to ease the maintenance task. This allows the rapid identification and replacement of the particular hardware device that failed without the need for extensive ground-support equipment.

Other notable accomplishments have occurred in the area of flat-panel displays. Five of the leading candidates for color, electronic display in flight are: the CRT; active-matrix LCD; thin-film electroluminescent (TFEL) display; light-emitting diode (LED) display; and plasma panel display (PDP). Of these candidates, the latter four are flat-panel technologies. The potential advantages of flat-panel technologies have already been provided in Figure 2. However, Figure 4 provides the key advantages and limitations of each technology as compared to the CRT. Although PDP technology is not represented in Figure 4, its advantages and limitations will be discussed below.

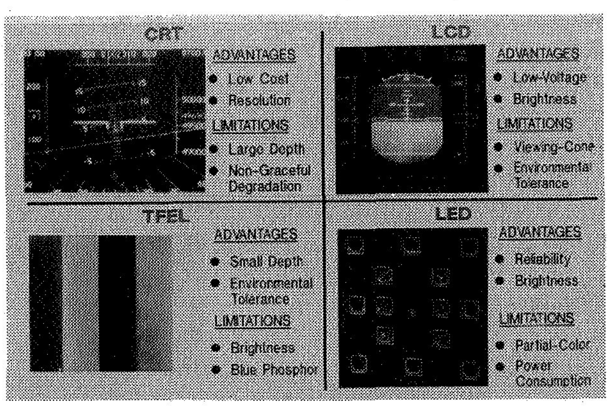

Figure 4. Four leading candidates for color, electronic flight display.

The color CRT provides the advantages of low cost (because of its maturity) and high resolution display. However, it has the disadvantages of large depth and non-graceful degradation. Further, it is susceptible to "washout" under high levels of ambient light. TFEL flat-panel technology has made great strides through research supported by the Army and LaRC. It has achieved full-color capability with small depth and environmental tolerance, however, its brightness limits its present use to low-ambient light environments. The color LED flat-panel technology has the advantages of very high reliability and brightness, but it is achieved at the cost of high power consumption. Further, full-color has not been achieved because of the lack of a bright blue LED capability. The color active-matrix LCD technology, described in the above section and shown in Figures 3 and 4, has the additional advantages of low-voltage operation and high brightness in conjunction with high resistance to "washout" in high-ambient light environments. Color PDP technology has the advantage of large screen size, however, it is achieved at the cost of additional weight in comparison with the other flat-panel technologies. Clearly, the color LCD technology is the leading flat-panel display candidate and has gained much confidence for potential use in both the Space Station MPAC and the Orbiter Glass Cockpit Upgrade, and will undoubtedly be a prime candidate for future advanced space transportation systems.

Another area of major accomplishment during the 1980's is the remarkable advancement in real-time graphics computers/generators. Laboratory-based graphics generators are now available that provide the following high-performance characteristics:

- RESOLUTION:	1280X1024 Pixels
- REFRESH:	30 or 60 Hz
- 3-D TRANSFORM:	500K/Sec.
- POLYGONS/SEC.:	100K (4-Sided)
- COLORS:	16M
- OTHER FEATURES:	Hidden Surfaces; Light Sources for Shading

Such generators are being employed in the Aero Human Factors R&T base efforts at LaRC since they offer, for the first time (in a package that might be considered small enough to ruggedize

for flight applications), the opportunity to present pilots flight control information in a high-fidelity, 3-D, "real-world" format that is easier for a pilot to assimilate and act upon. Figure 5, for example, shows one of the "real-world " formats that has been studied at LaRC.

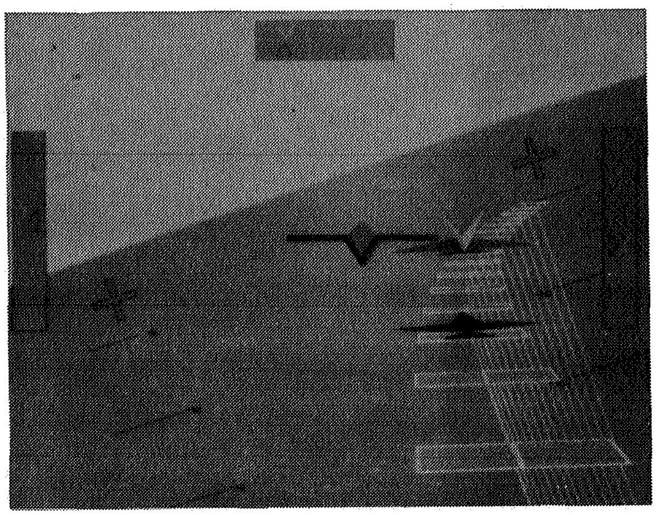

Figure 5.- Example of a "real-world" 3-D display format studied at LaRC.

The most prominent feature of this flight display is the "pathway-in-the-sky" symbology. This type of "real-world symbology has been shown, in both DOD and NASA research, to enable highly-precise flightpath control, especially for vehicles requiring complex curved flight paths.

The generation equipment described above also permits the real-time generation of displays, such as the format shown in Figure 5, in stereo, thus, enabling the exploitation of "stereopsis" or true-depth in "real-world" pictorial displays. Figure 6 shows the technique being used at LaRC for generating pictorial flight displays in stereo 3-D. Separate left- and right-eye views of the 3-D flight display are provided to the pilot through time-multiplexing using liquid-crystal goggles, as indicated by Figure 6. The pilot's brain fuses the disparate views into a 3-D image having true depth. Since each eye is shuttered at a 60 Hz rate (overall display frame rate is 120 Hz), there is no flicker. The technique does result in a reduction of vertical resolution by one-half, thus, providing a stereo display having 512 X 1280 picture elements (Pixels). Research at LaRC has shown that presenting pictorial displays in stereo can provide increased pilot performance and situational awareness.

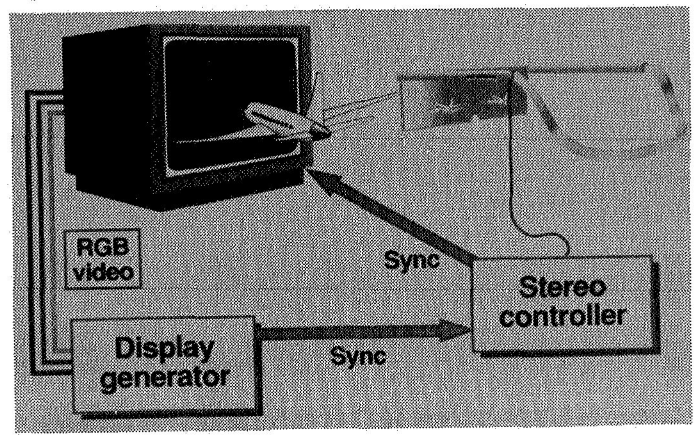

Figure 6.- Technique for generating real-time pictorial flight displays in stereo.

RESEARCH PROGRAMS AND FACILITIES

Several government and industry research programs around the United States are furthering the state-of-the-art in advanced D&C technology or are evaluating the products of advanced development. At NASA/JSC, flat-panel displays and hand controllers are evaluated in the D&C portion of the Advanced Systems Development Laboratory which is headed by Andrew Farkas. In addition to the color active-matrix LCD evaluations mentioned in the above section on Current State-of-the-Art, NASA/JSC will be evaluating a 17" full-color plasma flat-panel display to be received within the next year. This device is being developed under a Phase II Small Business Innovative Research grant from NASA. Another effort under way in this laboratory is the development of a hand controller test bed. Several examples of commercially available hand controllers have been procured and will be evaluated in this test bed, with a special emphasis on determining which hand controllers are best suited to perform robotics tasks with systems such as the Mobile Servicing Center, the Shuttle Remote Manipulator System, and the Flight Telerobotic Servicer. In addition to these activities, this laboratory has developed a simulated Flight Telerobotic Servicer Aft Orbiter Workstation, and a Space Station Multi-Purpose Applications Console (MPAC). These facilities are intended to be used for the determination of requirements for the actual systems.

NASA/JSC also has the Systems Engineering Simulator which is used to perform real-time man-in-the-loop simulations of most Shuttle and Space Station tasks. Functional mockups of the Shuttle Forward and Aft station cockpits, and of the Space Station Cupola are among the simulated systems.

NASA/LaRC and NASA/ARC have several interrelated research programs that have resulted or will result in advances in D&C technology. These programs and their relationships are shown in Figure 7.

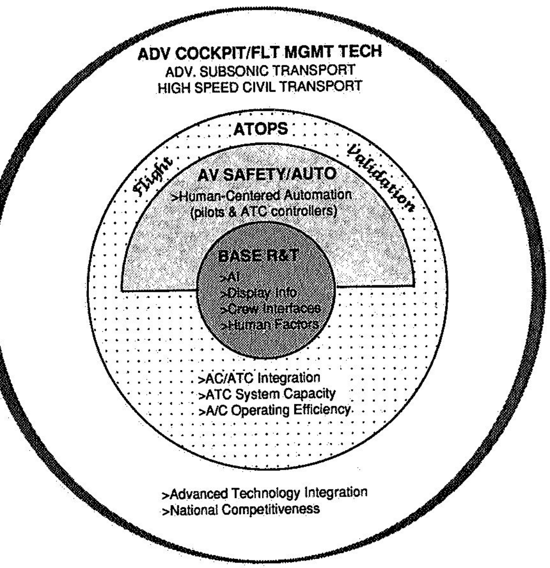

Figure 7.- Research programs at LaRC and ARC related to advanced D&C technology.

The Aero R&T Base program has primary thrusts in the areas of artifical intelligence (knowledge-based systems for pilot aiding), in integration of display information, in advanced crew interface technology, and in human factors methodologies and guidelines for the application of these new technologies. The Aviation Safety/ Automation program is a joint program with Ames Research Center (ARC) which has the thrust of providing advanced human-centered automation technologies and application guidelines for both pilots and air traffic controllers. The ATOPS (Advanced Transport OPerating Systems) program has the research thrusts of improving aircraft/ATC systems integration, increasing ATC system capacity, and enhancing aircraft operating efficiency. The ATOPS program, which employs an advanced B-737 Transport Systems Research Vehicle (TSRV), to be discussed in more detail below, provides a testbed for flight validation of advanced concepts and technology. The Advanced Cockpit/Flight Management Technology program (also a joint effort between LaRC and ARC) is a proposed new initiative which would emphasize both advanced subsonic transports and high-speed civil transport applications and would provide the mechanism for integration of advanced concepts and technologies emanating from the other programs and for providing an advanced technology base which would enhance national competitiveness. Much of this technology base, in the area of advanced D&C, will be applicable to future space systems.

NASA/LaRC and NASA/ARC have extensive cockpit simulation facilities which support the above and other research programs. At LaRC the facilities include a Visual Motion Simulator(VMS), a DC-9 Simulator, an "all glass" Advanced Concepts Simulator (ACS), a Transport Systems Research Vehicle (TSRV) Simulator and companion TSRV B-737 research aircraft, and a Crew Station Systems Research Lab with associated Advanced Display Evaluation Cockpit (ADEC) simulator and Aircraft Cockpit Ambient Lighting Simulation System (ACALSS). At ARC the facilities include a Flight Simulation Complex and a Man Vehicle Systems Research Facility. Two of the major tools within these facilities are the Vertical Motion Simulator and the Advanced Concepts Simulator (ACS). The ACS at ARC is a companion simulator to the ACS (mentioned above) at LaRC (see Figure 8) and

Figure 8.- LaRC Advanced Concepts Simulator

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will be used for joint studies with LaRC, particularly in the area of the Aviation Safety/ Automation program. The ACS at LaRC is shown in Figure 8 along with an example of bioinstrumentation used by the Human Engineering Methods group to assess the physiological impact of new automation and D&C technology on humans.

The TSRV B-737 aircraft facility at LaRC is quite unusual in that the research cockpit, a full-color, "all glass," electronic flight deck, is located aft of the standard cockpit and can be utilized to fly the aircraft in a variety of research studies, including approach and landing maneuvers. The airborne TSRV Aft Flight Deck is shown in Figure 9.

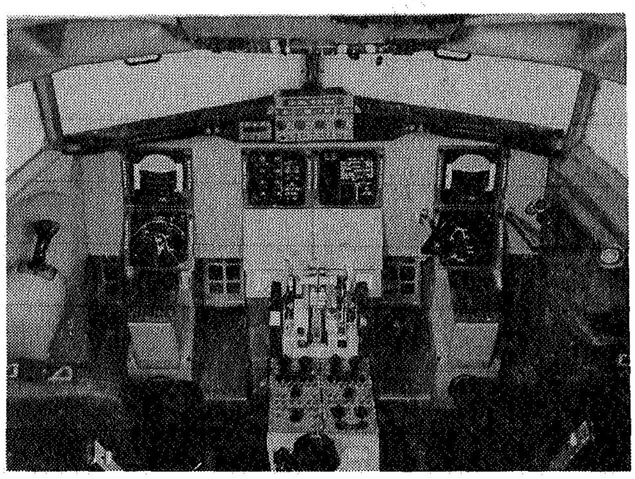

Figure 9.- The LaRC TSRV Aft Flight Deck onboard the B-737 aircraft.

The TSRV aircraft represents a unique flying testbed that has already been used extensively in studies investigating methods for improving the safety, efficiency, and capacity of the National Airspace System, as well as for landing studies, investigating helmet-mounted display (HMD) technology, in support of the National AeroSpace Plane (NASP) program.

Other research programs and associated facilities of interest to this assessment include the Super Cockpit Program , headed by Dean Kocian of the Air Force Wright Research and Development Center (WRDC), and the Cockpit Integration Directorate program, headed by Terry Emerson of WRDC. The former program has the thrust of providing the technology for an integrated, "virtual cockpit" through use of advanced display generation and HMD technologies. The virtual interface of the Super Cockpit Program is depicted by Figure 10.

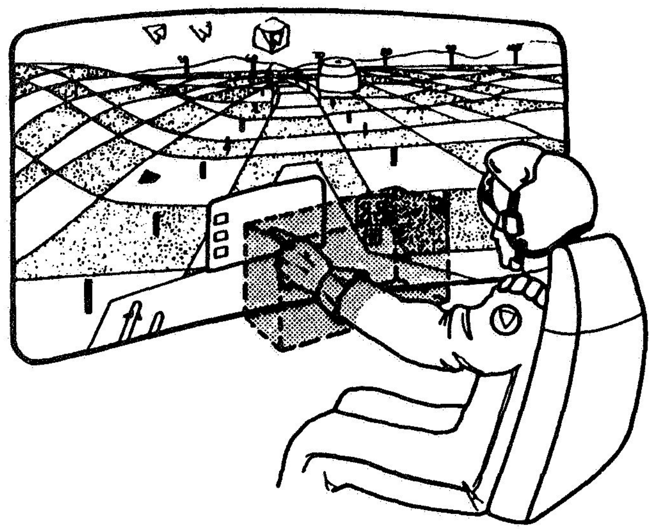

Figure 10.- "Virtual Cockpit" provided by HMD technology in the Super Cockpit Program.

The latter program (Cockpit Integration Directorate) is doing research on pictorial flight display formats for integration of information, on stereo 3-D displays, and on color LCD technology for military applications. A major facility used for this research is their "Magic Cockpit," an "all-glass" fighter cockpit with rapidly reconfigurable display capability. WRDC has also supported "Big Picture" research at McDonnel Aircraft, under Gene Adam, the thrust of which is to study the benefits of providing enhanced situational awareness and planning information to pilots of tactical aircraft via HMD's and large-screen electronic displays. Another important government research program is the Pilot's Associate Program, headed by Doc Dougherty at DARPA. This program is investigating the extensive application of artifical intelligence to future military cockpits in the form of an "electronic associate."

FUTURE TRENDS

The 1990's will undoubtedly bring further advancements in the the fields of voice, touch, and hand-controller input technologies, in flat panel technologies, in HMD's, in artificial intelligence techniques, and in flight worthy graphics generators capable of integrated, "real-world" pictorial display formats.

In voice technology, for example, the 1990's should see further enhancement in continuous-speech, speaker-independent voice recognition technology which will result in systems that allow the operator to keep his/her hands on the controls during critical or dangerous operations. Human factors research has found that voice recognition systems are much more effective when the operator is allowed to speak in a continuous, comfortable manner with commonly used expressions rather than speaking with isolated words, as is required in older voice recognition systems.

Large-screen flat-panel or projection display technology, coupled with advances in real-time graphics generators, may enable the type of advanced-concept future cockpit depicted in Figure 1, wherein total integration of the crew's information requirements is achieved through panoramic, wide-field-of-view, integrated pictorial displays. Already, LaRC is developing a flexible panoramic display research system (depicted in Figure 11) employing dual, full-color, CRT projectors in conjunction with rapid display prototyping graphics systems and software to explore the advantages and limitations of panoramic and large-screen, reconfigurable display concepts. More extensive R&D will be enabled in these areas by the proposed ARC/LaRC Advanced Cockpit/Flight Management Technology program.

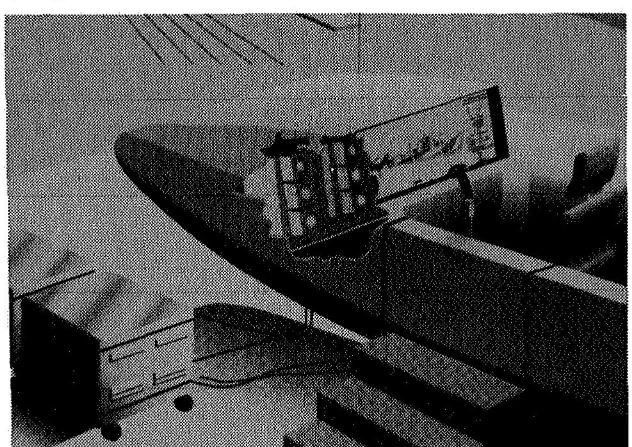

Figure 11.- Large-screen/panoramic display research system being developed at LaRC.

The Human Factors R&T base and Aviation Safety/Automation programs at LaRC and ARC should produce significant advances in application of human-centered automation and knowledge-based systems in aiding crews of future vehicles. Already, the efforts have produced important advances in intelligent cockpit aids for fault management, flight planning and replanning, flight phase management, and check-list and advisory systems.

Also, DARPA has launched an effort to get the U.S. up to speed in the area of High-Definition Television (HDTV), a field which has undergone extensive development in Japan and Europe. DARPA has funded several commercial sources to do research in this area which will most likely result in further advancements in large-screen projection and flat-panel technologies. Further, the HDTV technology is indicated for many applications which require live video images, such as teleoperations and telerobotics.

TECHNOLOGY ISSUES

This next section will attempt to address technology issues specific to the area of advanced D&C for space transportation systems. The first issue is the maturity of advanced display media. CRT's have for many years been the basic display device for image generation, including computer-generated raster graphics. The CRT and its associated raster-scan generators have evolved dramatically throughout their lifetime to provide a high level of reliability, photographic clarity, high-speed animation, and an unlimited range of colors. However, functional requirements have also evolved, and these changes have had effects on display device technology. As indicated above, various technologies for producing visual images have emerged that may eventually replace the CRT.

For most of the space transportation systems, such as the Orbiter Glass Cockpit and the Space Station MPAC, it is necessary to include displays which consume very little power and are sunlight legible in approximately 10K ft-candles of ambient light. Currently, the active-matrix LCD is the front runner in the flat panel display race, with TFEL and plasma lagging somewhat behind. However, it is expected that one or more of these technologies will be ready to meet the needs of advanced transportation systems of the 1990's.

Another key technological issue is the method by which the human interacts with the displays and controls system. In the past such methods required the use of, for the most part, dedicated controls and switches for man-machine operation. Meaningful research has already been performed on how multi-functional controls, such as keyboards, touch overlays, voice recognition, and programmable, variable-legend switches, may decrease the number of dedicated items, without affecting operator efficiency, to provide a clean and uncluttered work area. However, care must be taken to avoid man-machine interaction techniques which result in an unreasonable amount of heads-down time during critical operations such as aircraft take-off and landing. For example, some pilots have criticized the Control Display Units (CDU) flown in modern cockpits for this reason. These devices consist of a small scratch-pad display and a multi-function keyboard which at times require several keystrokes to initiate certain operations should changes occur in the flight plan. An additional concern is the inevitable impact that electronic displays and controls (i.e. all-glass cockpits) will have on crew training. Flight crews will obviously have to be re-trained to become proficient with these new systems.

Another area which requires further study is the area of advanced display symbology. The goal is to give the pilot or operator an easily interpreted indication of the vehicle state and onboard systems status. Visual and auditory means are used to provide information to the human operator. Visual images, however, have the highest content of information that may be interpreted within the shortest amount of time. This characteristic is even further enhanced when such information is preprocessed into a form in which the human brain can grasp the information content with minimal mental interpretation. This processing is done with a graphics processor, which consists of some sort of display generator driven by a computer designed to generate graphical and alphanumeric output. Graphics generators range in capabilities from mere text information displays to high-end, real-time 3-D computer image generators (as described above). To achieve maximum capabilities with minimal hardware, a flexible graphics system must be incorporated into the man-machine system architecture which will be capable of meeting present needs, yet will be adaptable for more advanced needs.

The area of artificial intelligence for cockpit automation is one which requires further research. The goal is to develop techniques to monitor and assist the operator rather than to replace him/her and to anticipate future problems rather than giving a warning once a fault or error has occurred. The danger of making the crew bored or mere machine-minders must be avoided through the judicious selection of tasks to be automated. Clearly, computers lack the creative ability and cognitive characteristics which permit humans to interpret and integrate relationships between data for working around faults or problems which may not have been foreseen. However, properly designed expert systems could offer capabilities for safety and efficiency unmatched by today's systems.

Before artificial intelligence can be successfully utilized in space transportation systems, a cultural change will be required at NASA to overcome the resistance to this technology. The advent of advanced D&C coupled with expert systems technology could produce more autonomous vehicles and greatly reduce requirements for large ground facilities with "marching armies" to support them.

SPACE TRANSPORTATION SYSTEM APPLICATIONS

The following paragraphs will attempt to identify the space transportation systems which could benefit from the advanced display and control concepts previously discussed. First is the proposed Orbiter Glass Cockpit Display Upgrade Program, which is a candidate for Assured Shuttle Availability (ASA) funding for 1991. Today's Shuttle cockpit consists of electromechanical flight instruments which were designed in the early 1970's and have been operating for over ten years. As a result of their age and extensive use, these mechanical devices have gradually begun to show signs of wearout and have become an increasing maintenance problem. They are experiencing an increasing number of failures, and the

problem is further complicated due to parts and skills obsolescence and limited availability of spares. In addition to these problems, the Multipurpose CRT Display System (MCDS), which consists of four monochrome 5" x 7" displays and four Display Electronics Units (DEU) has had a history of extremely high failure rates. The baseline design of the proposed Orbiter Glass Cockpit Display Upgrade program attempts to eliminate the problems of both of these sets of hardware by evolving to an advanced display system which utilizes state-of-the-art flat panel flight displays and modern processors integrated on a high speed data bus. Similar systems are already flying in several commercial and military aircraft cockpits. The proposed panel layouts and architecture are shown in Figures 12 and 13, respectively.

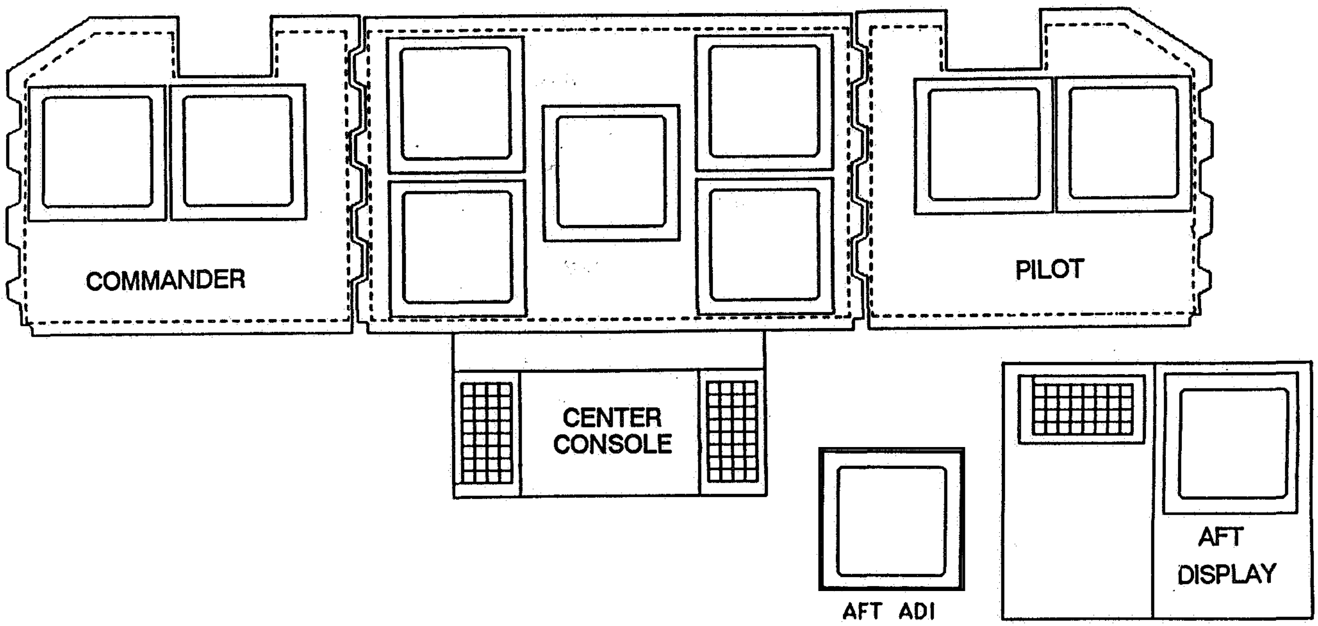

Figure 12.- Orbiter conceptual glass cockpit layout.

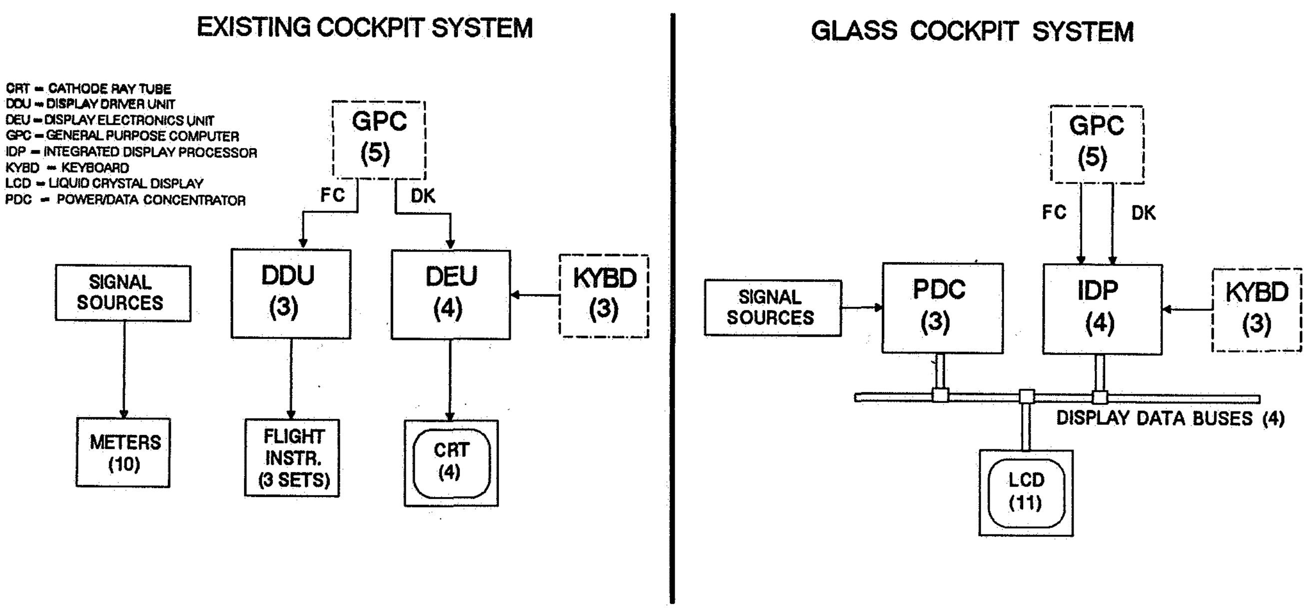

Figure 13.- Orbiter glass cockpit conceptual baseline architecture.

Some of the goals of the new system are that it be transparent to the orbiter General Purpose Computer (GPC) hardware and software, that it exhibit improved reliability and fault tolerance and reduced life cycle costs, and that it employ standard interfaces for subsequent incorporation of advancing technology. It should also have sufficient growth margins to support new functions which may arise in the future. One potential upgrade to this proposed system which has received some discussion is the implementation of a combined aft cockpit manipulator workstation. When one considers that the Shuttle Remote Manipulator System (RMS), the Space Station Freedom (SSF) RMS, the Flight Telerobotic Servicer, the Canadian Special Purpose Dextrous Manipulator, the Satellite Servicer, and the OMV must all be controlled from the orbiter, it is quite apparent that insufficient real-estate exists for the use of special-purpose displays and controls for all these systems. It would be quite feasible to install additional hardware on the Glass Cockpit data buses to implement a workstation capable of handling all these devices.

The SSF Multi-Purpose Applications Console (MPAC) and the Assured Crew Return Vehicle - Crew Emergency Return Vehicle (ACRV - CERV) are other near-term programs which are benefiting from research and accomplishments in the area of advanced D&C. The current MPAC design employs modern processors, three 15" color flat panel displays, a QWERTY keyboard, a trackball, and two six degree-of-freedom force-reflecting hand controllers. The ASRC - CERV design employs 2 flat panel displays, a keyboard, modern processors, and other dedicated displays and controls.

Although conceptual designs for the displays and controls which may be needed for far-term programs such as the manned Lunar and manned Mars missions have not yet been defined, it is certain that they well incorporate advances made during the next several years. The authors envision very large multi-function flat panel pictorial displays driven by real-time 3-dimensional graphics processors, multifunction controls (i.e. minimal use of hard-wired single function switches), and extensive use of human-centered automation and expert systems technology.

RECOMMENDATIONS

Two "holes" were identified during the STATS proceedings. The first one is that present funding levels in the research and technology base and in advanced development programs do not provide the timely capability to influence or adapt commercial D&C technology to the specialized needs of space. The problem is further compounded by the fact that NASA only procures a relatively small quantity of the end-product. The second hole is the need for a focused technology program to integrate advances being made in display devices, graphics engines and pictorial formats, expert systems, and human-centered automation to provide technology readiness and validate projected gains in safety and operational efficiency for future space transportation systems. To fill the first "hole," it is recommended that funding levels for advanced D&C research and development be increased. To fill the second "hole," it is recommended that early development be undertaken at JSC on a "next generation" orbiter experimental cockpit facility.

SUMMARY

An attempt has been made in this paper to discuss the current state-of-the-art of D&C technology, to identify key issues and accomplishments, and to show where the technology is headed. In addition, cultural changes that would facilitate the migration to advanced D&C technology in advanced programs and the general applicability of advanced D&C to specific near-term and far-term space transportation systems have been discussed.

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ADVANCED SENSORS AND INSTRUMENTATION

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM

Williamsburg, VA
November 7-9, 1989

ADVANCED SENSORS AND INSTRUMENTATION

WHITE PAPER

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ADVANCED SENSORS AND INSTRUMENTATION

WHITE PAPER

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December 6, 1989

Background

NASA is currently investigating the readiness of Advanced Sensors and Instrumentation to meet the requirements of our nation's new initiatives in space. Pre-symposium, Space Transportation Avionic Technology (STATS), ad-hoc discussions were focused on identifying strategic sensor and instrumentation technologies. The content of this paper resulted from discussions between members of the technical staffs at Langley, Johnson, Marshall, and Rockwell International. Summary suggestions per organization are attached as appendixes to this white paper.

The STAT presentation was focused around the 8 quad charts, see Figures 1 and 2.

Not knowing the specific technical objectives of individual missions, the group identified and discussed the following strategic technologies:

- Smart and nonintrusive sensors
- On-board signal and data processing
- High capacity and rate adaptive data acquisition systems
- On-board computing
- High capacity and rate on-board storage
- Efficient on-board data distribution
- High capacity telemetry
- Ground and flight test support instrumentation
- Power distribution
- Workstations, video/lighting

The goal of this white paper is to capture the substance of the presentation and technology discussions during the subpanel meeting.
The requirements for higher fidelity data (accuracy, frequency, quantity, spatial resolution) in hostile environments will continue to push the technology developers and users to extend the performance of their products and to develop new generations. In some technology areas, this process may acquire a strong active leadership from NASA. Thus, there is a need for a workshop just for Advanced Sensors and Instrumentation.

Smart and Nonintrusive Sensors

Forecasts for the future include third and fourth generation sensor technology. Sensors with digital outputs, at sensor location, in engineering formats for distribution. Sensors with advanced dedicated signal processing such as fast fourier transform and digital filters at the sensing location. In many applications the sensors will have to be embedded in the surface or structure.

The nondestructive Measurement Science Branch, at Langley Research Center, is currently investigating innovative techniques in making nonintrusive measurements, for example, see Figures 3 through 6. Other nonintrusive techniques highlighted at the symposium included laser-based air data, Rendezvous/proximity, large space structures, and planetary surveys systems, see Figures 7 and 8.

Langley Research Center has initiated development studies for a laser-based air data system to replace the currently used pilot/static pressure, angle-of-attack, and angle-of-sideslip vane measurement system. Application of this system could extend to space transportation vehicles, and compliment the Shuttle Entry Air Data System (SEADS). Additional research funds are needed to make required advances in optics, lasers, and detectors to bring laser air data to fruition. Other key sensor areas discussed include: vehicle health performance monitoring, global position sensing, and guidance navigation and control.

Signal and Data Processing Instrumentation

As with other instrumentation, signal conditioning must be optimum in utilization of weight, volume, and power. Advances in micro-miniaturization; and hybrid electronics are enabling intelligent processing at the measurement location. Thus, allowing on-site bandwidth reduction and digital outputs. Continued improvements along these lines provide efficient bandwidth utilization and weight reduction using state-of-the-art data buss technology.

High Capacity and Rate Adaptive Data Acquisition

Current sensing instrument requirements (Eos) are exceeding the TDRSS data rates, see Figure 9. Therefore, the trend will be to develop on-board bandwidth reduction techniques, high capacity and high rate data buffering storage devices, and higher capacity communication systems. The signal and data processing instrumentation will have to be artificial intelligence/ expert system-based. These systems will have to manage the limited bandwidth very efficiently.

System Checkout, Calibration, and Test Ability

Throughout the discussions, the questions seem to lead to assurance testing, validation, testability, and maintainability. The general concensus was that Advanced Sensors and Instrumentation developers should be brought to the system design table at the start of the program and not as an afterthought. Testability and maintainability must be built into the original designs and facilitate calibration, check-out, and validation during operational phases.

Summary

There were many good questions asked and discussions focused around typical engineering concerns:

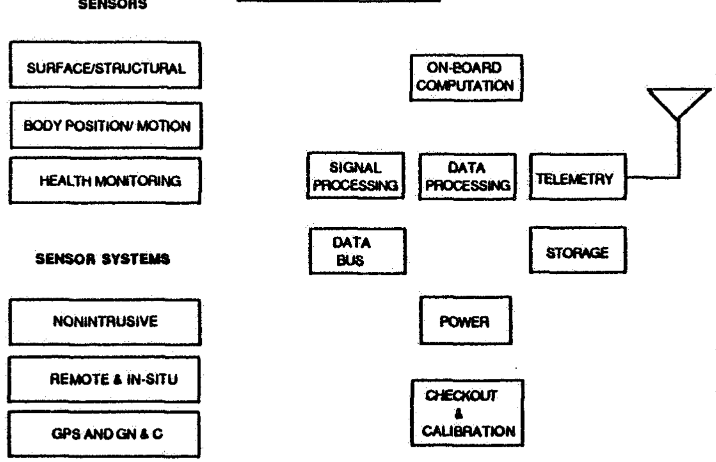
- Increased reliability and accuracy for performance evaluation
- How to pre-flight, checkout, calibrate, and post-flight maintenance
- Reduce quantity to cables for data collection/sensor interrogation
- How to validate expert systems?
- Intelligent data reduction on-board

Most of the technical issues discussed are captured in the quad charts. Major contributors' on-going research areas are displayed in the appendixes.

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
FLIGHT ELEMENTS

ADVANCE SENSORS & INSTRUMENTATION

CONCEPT



MAJOR OBJECTIVES

LOW, WEIGHT, VOLUME, POWER & COST

	CURRENT CAPABILITY	NEW REQUIREMENTS
SENSORS - AIR DATA - TRANSITION - PRESSURE/TEMPERATURE INSTRUMENTATION NONINTRUSIVE AIR DATA		HIGH ACCURACY HIGH SPATIAL DENSITY HIGH FREQUENCY HIGH RELIABILITY
SMART DATA SYSTEMS		300Mb/sec
ON-BOARD PROCESSING		DATA COMPRESSION
ON-BOARD COMPUTATION		DATA PRODUCTS
ON-BOARD STORAGE		> TERABIT
DATA BUS		
CHECKOUT/CALS/AUTO RANGE		
POWER		
SOLID STATE LASERS		2 JOULE SOLID STATE
LIGHT WEIGHT OPTICS		
LG REFLECTORS/ANTENNAS		
SMART STRUCTURES/SERVOS		NDE
DETECTORS		
CRYOGENICS		20K COOLERS

KEY CONTACTS

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G.HARMON (EH6)	
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K.PETERSON (NOVA SENSORS)	
R.MORRISON (ROCKWELL)	818-718-4456

FACILITIES

CLEAN ROOMS	EMI/EMC
ENVIRONMENTAL CHAMBERS	CAD/CAE & ASIC
THERMO VAC CHAMBERS	LASER LAB
CALIBRATION	DETECTOR LAB
NDE LABS	COMPUTATIONAL SUPPORT
SENSOR LABS	TEST BED ENGINES
ENVIRONMENTAL	TURBINE BLADE DIAGNOSTIC TEST
R & QA	
MICROELECTRONIC/MATERIALS	

FIGURE 1

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
FLIGHT ELEMENTS

ADVANCE SENSORS & INSTRUMENTATION

TECHNOLOGY ISSUES:

- O SMART SKINS - FIBEROPTIC TRANSDUCERS & TRANSMISSION LINES EMBEDDED IN ADVANCED COMPOSITES
- O MICRO-MACHINED TRANSDUCERS - EMPLOYING CLASSICAL SEMICONDUCTOR PROCESSING TECHNIQUES TO BUILD MECHANICAL STRUCTURES & TRANSDUCERS
- O SMART TRANSDUCERS - INTEGRATION OF A TRANSDUCER, SIGNAL CONDITIONERS, PROGRAMMABLE EMBEDDED MICROCONTROLLERS
- O ADVANCED INSTRUMENTATION - INTEGRATION OF SMART TRANSDUCERS INTO A DISTRIBUTED BUS OR FAULT TOLERANT LOCAL AREA NETWORK (LAN)
- O HYBRID ELECTRONICS & SURFACE MOUNT TECHNOLOGY
- O INTEGRATION OF DIVERSE TRANSDUCERS & SIGNAL TYPES INTO SMART TRANSDUCER MODULE
- O APPLICATION SPECIFIC INTEGRATED CIRCUIT (ASIC) DESIGN CAPABILITY TO MINIMIZE WEIGHT, POWER, & VOLUME PARAMETERS
- O THIN FILM SENSORS
- O HIGH TEMPERATURE STRAIN SENSORS
- O SMART, MINIATURE & RELIABLE DATA ACQUISITION SYSTEMS (DAS)
- O ON BOARD DATA PROCESSING
- O ON BOARD COMPUTATION
- O ON BOARD STORAGE
- O ADVANCED DATA TRANSMISSION
- O LASER - BASED RENDEZVOUS SYSTEMS
- O 2 MICRON LASERS FOR EYE-SAFE AND WINDS
- O LIGHT WEIGHT OPTICS FOR WIND SHEAR LIDAR
- O CRYOGENICS : DEVELOP 20K COOLERS FOR SOLVING MOST DETECTOR PROBLEMS
- O LARGE REFLECTORS/ANTENNAS
- O DEVELOP ELECTROMAGNETIC MEASUREMENT, MODELING, INJECTION & DETECTION SENSORS

CANDIDATE PROGRAMS:

UPGRADE OF ORBITER MODULAR AUXILIARY DATA SYSTEM (MADS)

UARS

EOS

SHUTTLE C

SPACE STATION FREEDOM

ELV

MISSION TO PLANET EARTH

MANNED MISSION TO MARS

LUNAR BASE

MAJOR ACCOMPLISHMENTS

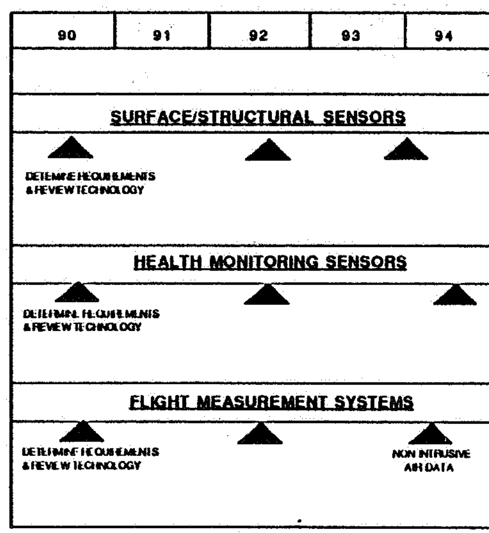
LIDAR

OPTICAL DISK

HIGH PRESSURE STAND ALONE PRESSURE MEASUREMENT DEVICE

OPTICAL PLUME ANOMALY DETECTION SYSTEM

SIGNIFICANT MILESTONES



GOALS

- O SMART SENSORS
- O SMART SKINS
- O SMART, SMALL & RELIABLE DAS
- O ON BOARD DATA PROCESSING
- O ON BOARD COMPUTATION
- O ON BOARD STORAGE
- O ADVANCED DATA TRANSMISSION
- O SMART STRUCTURES
- O LASER APPLICATIONS
- O INTERFACE REQUIREMENTS DEF.
- O NDE

FIGURE 2

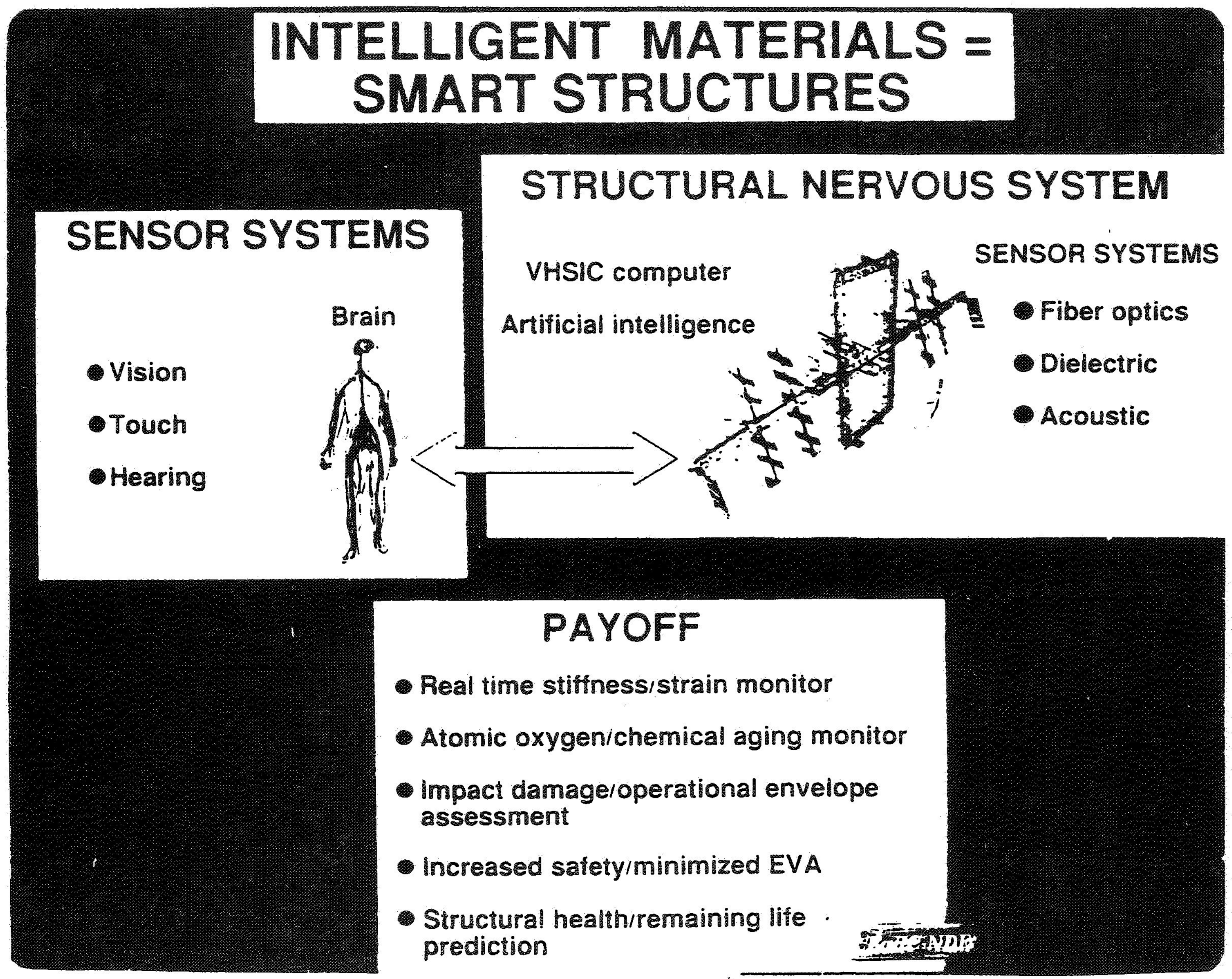
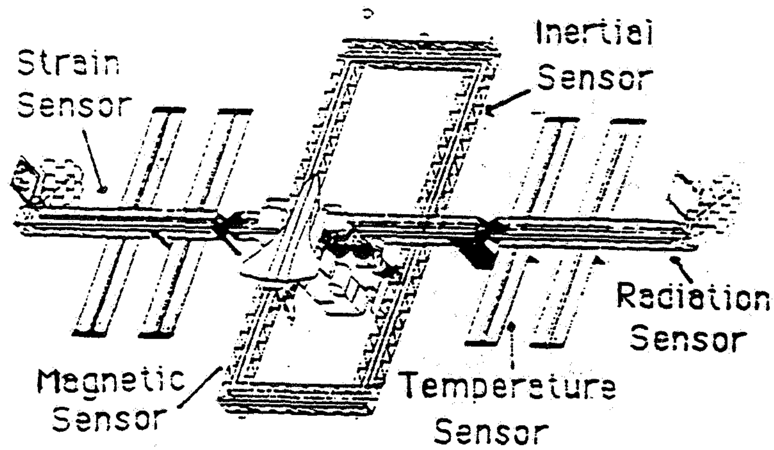

INTELLIGENT MATERIALS = SMART STRUCTURES
SENSOR SYSTEMS
Brain
● Vision
● Touch
● Hearing
STRUCTURAL NERVOUS SYSTEM
VHSIC computer
Artificial intelligence
SENSOR SYSTEMS
● Fiber optics
● Dielectric
● Acoustic
PAYOFF
● Real time stiffness/strain monitor
● Atomic oxygen/chemical aging monitor
● Impact damage/operational envelope assessment
● Increased safety/minimized EVA
● Structural health/remaining life prediction

FIGURE 3

FIBER OPTIC SENSORS

Space Station Requirements

Type	Purpose	Daily Requirements
Linear Acceleration	Magnitude	7.5×10^{-4} g
	Frequency	1 to 4 hz
Strain Level	Magnitude	2.5×10^{-6}
	Frequency	.1 to .5 hz



Theoretical Resolution Limits of Fiber Sensors

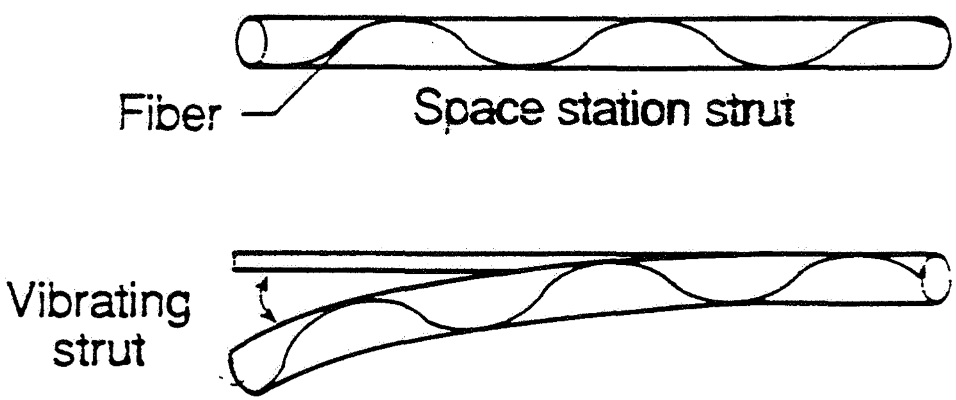
Strain	10^{-12}	in/in
Magnetic	10^{-12}	Gauss
Electric	10^{-4}	V/M
Rotation	10^{-6}	Dg/Hr
Temperature	10^{-8}	Dg/C
Acceleration	10^{-8}	G'S
Acoustic	10^{-6}	Pa

Advantages Of Fiber Optics

High Bandwidth	0.1 To 100 Ghz
Small, Lightweight	50 To 500 um O.D.
Electrical Immunity	E. M. I. , E. M. P.
Low Attenuation	0.2 To 5db/Km
Geometric Flexibility	

FIGURE 4

FIBER OPTIC SENSORS FOR INTELLIGENT MATERIALS



Benefits

- Low mass sensor
- Integrated with structural material
- No EMI
- Distributed sensor
- Multiple function fiber

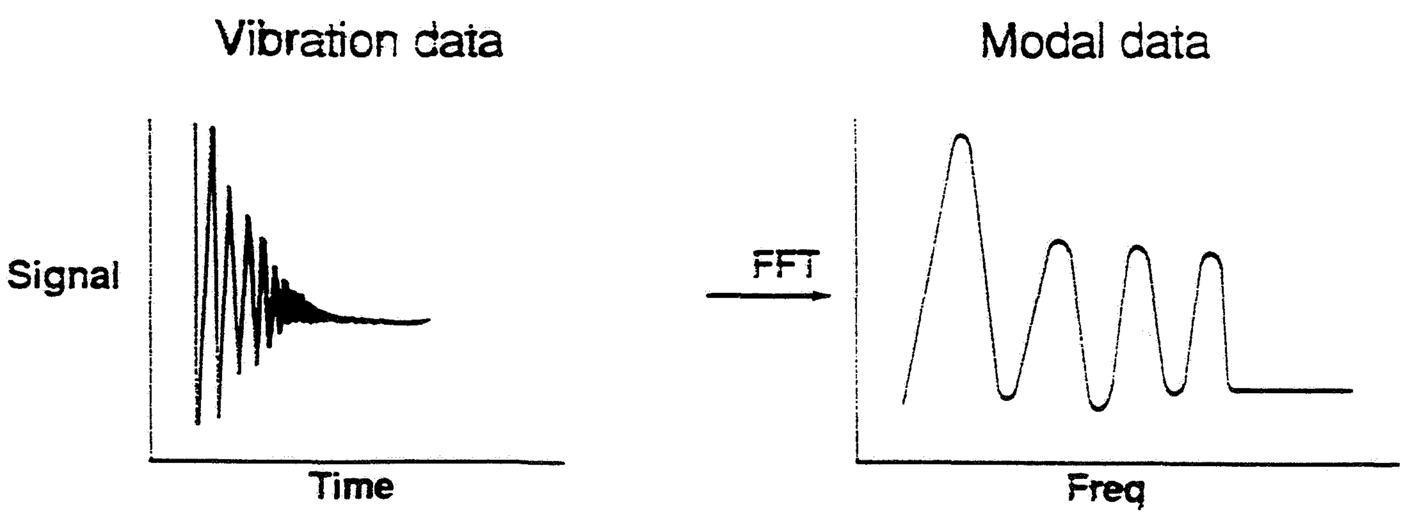
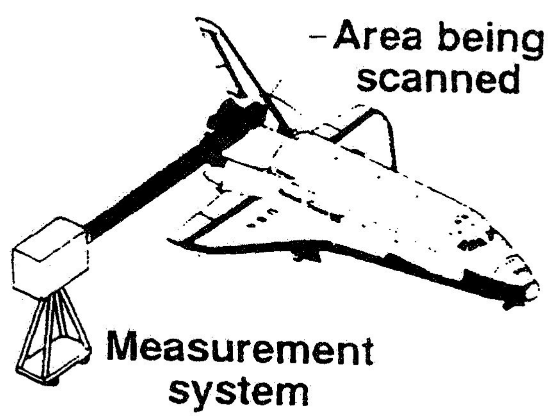


FIGURE 5

NDE BY
THERMAL DIFFUSIVITY IMAGING

Advantages:
- Noncontacting
- Computer controlled
- Scans large complex geometries

**Remote Measurement
In Field Setting**



**Thermal Relationships
In Scanned Area**

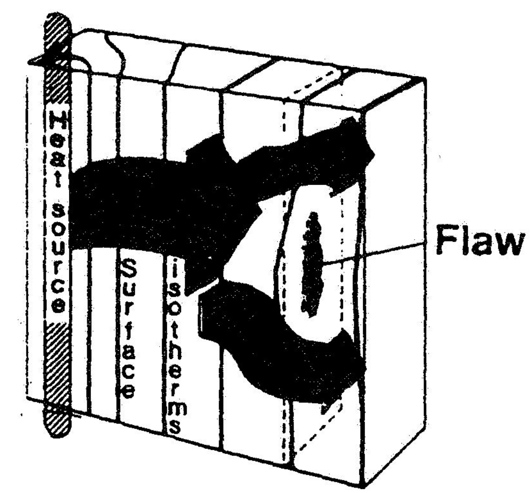
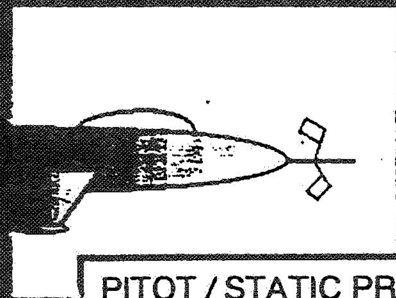
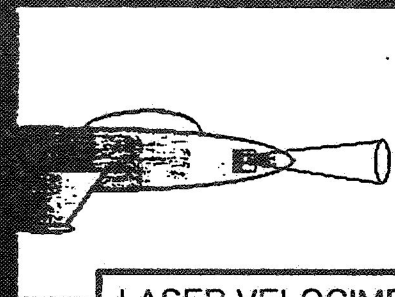


FIGURE 6

LASER BASED AIR DATA SYSTEM





- NON - INTRUSIVE MEASUREMENT OF SUPERSONIC / HYPERSONIC FLOW
  - AIR DATA
  - BOUNDARY LAYER STUDIES
  - CODE VALIDATION
  - ENGINE INLET FLOW FIELDS
- BUILD ON EXISTING DIAGNOSTIC STUDIES
  - SRA Inc. , IRD, SANDIA, LOCKHEED/SANDERS, STANFORD
- FOCUS AIRBORNE LASER DEVELOPMENT CAPABILITIES TOWARD AIR DATA MEASUREMENTS
  - EXTEND LaRC WIND SHEAR LIDAR EFFORT

FIGURE 7

SOLID-STATE LASER SENSORS FOR SPACE EXPLORATION

- o THE SOLID-STATE LASER TECHNOLOGY BASE DEVELOPED FOR SATELLITE AND AIRCRAFT BASED ENVIRONMENTAL SENSORS IS IMPORTANT TO SPACE EXPLORATION
  - EXAMPLES OF ADVANCED SENSOR CONCEPTS FOR RENDEZVOUS/PROXIMITY OPERATION, LARGE SPACE STRUCTURES, PLANETARY SURVEYS

- o RENDEZVOUS/PROXIMITY SENSORS
  - LASER RADAR WITH DIODE LASERS/DIODE LASER PUMPED SOLID-STATE LASERS
  - IMAGE RECONSTRUCTION FROM LASER RADAR REFLECTIVE PROJECTIONS (CONCEPTS ADAPTED X-RAY ABSORPTION COMPUTER ASSISTED TOMOGRAPHY), COMPUTER VISION

- o LARGE SPACE STRUCTURE DISTORTION SENSORS
  - LASER RADAR WITH DIODE LASER/DIODE LASER PUMPED SOLID-STATE LASERS
  - SOLID-STATE LASERS WITH LONG FIBER OPTICS/FIBER LASER AMPLIFIERS AND/OR LOCAL LASER FIBER SENSORS

- o PLANETARY SURVEY SENSORS
  - SOLID-STATE LASER RADAR RANGING IMAGE RECONSTRUCTION
  - COMPUTER VISION, ROBOTICS NAVIGATION
  - WIDE WAVELENGTH RANGE TUNABLE SOLID-STATE LASER RADAR COLOR REFLECTOMETER, ROBOTICS

FIGURE 8

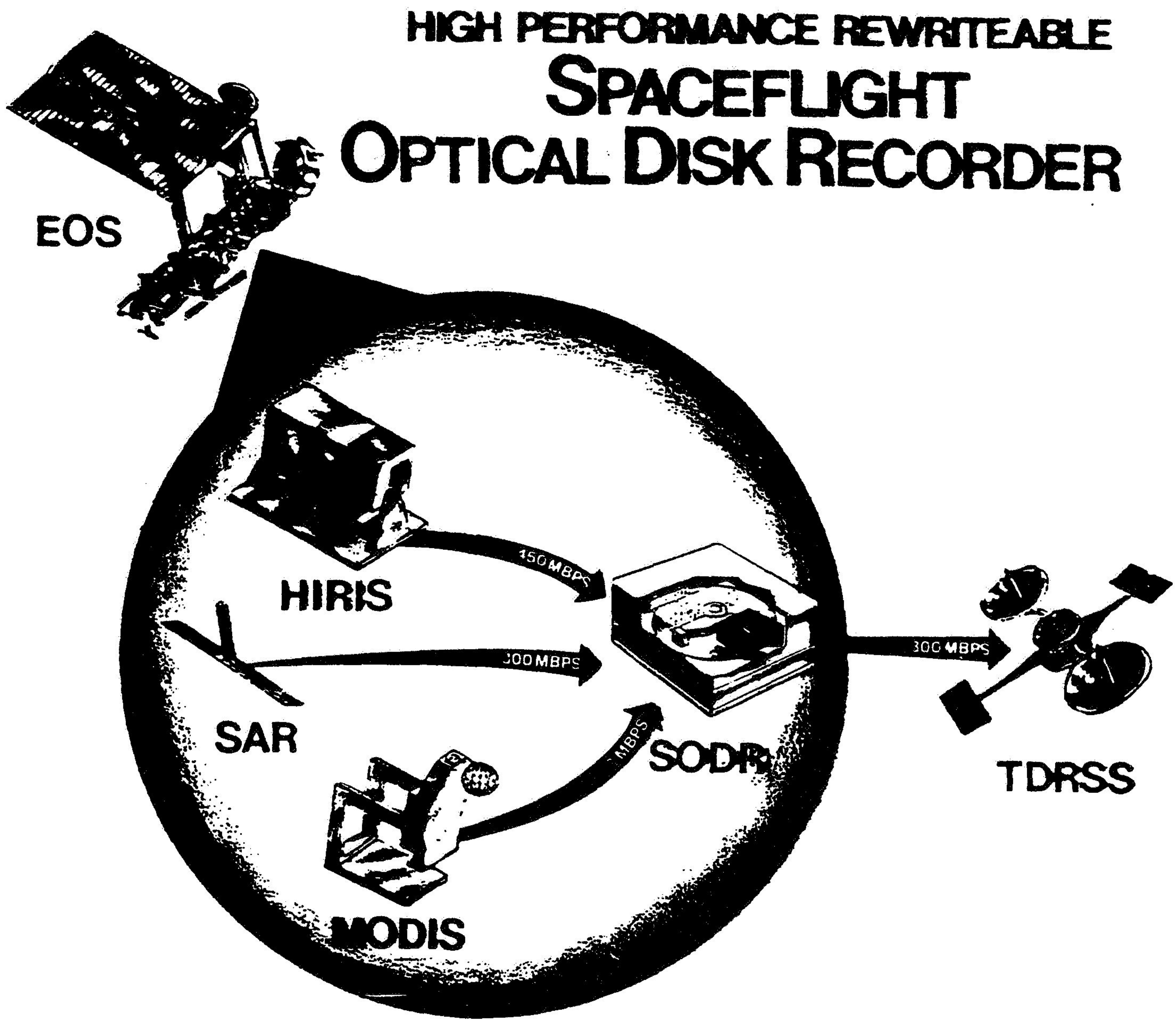

HIGH PERFORMANCE REWRITEABLE
SPACEFLIGHT
OPTICAL DISK RECORDER
EOS
HIRIS
150 MBPS
SAR
300 MBPS
MODIS
MBPS
SODR
300 MBPS
TDRSS

FIGURE 9

APPENDIX 1

Kevin R. Douglas

Lockheed
Engineering & Sciences Company

ADVANCED SENSORS & INSTRUMENTATION

ADVANCED SENSORS & INSTRUMENTATION

Micro-gravity Transducers
Thin Film Transducers
Fiber Optic Transducers and Transmission Lines
Smart Skins: Fiber Optic Transducers and Transmission lines embedded in advanced composites;
Micro-machined Transducers: Employing classical semiconductor processing techniques to build mechanical structures and transducers;
Smart Transducers: Integration of a transducer, signal conditioning, programmable embedded micro-controllers;
Advanced Instrumentation: Integration of Smart Transducers into a distributed bus or fault tolerant Local Area Network (LAN);
Hybrid Electronics and Surface Mount Technology

MAJOR OBJECTIVES

Low Cost
Low Weight
Small Volume
Low Power
Higher Accuracy: Local Signal Conditioning and Data Conversion
Self Calibration, Zero Offset, and Zero Drift
Function in Remote Locations and Severe Environments
Adaptable to future data processing requirements (Digital Input/Output)
Provides a technology base for next generation instrumentation systems

KEY CONTACTS

R. Calloway/LaRC
M. Gaudiano/JSC EH6
G. Harmon/JSC EH6
K. Douglas/Lockheed
K. Peterson/Nova Sensors

MAJOR MILESTONES

Review Technology (1990)
Establish Interface and Architectures
Define Hierarchy of Functions (1991)
Analysis and Demo in the Laboratory (1992)

TECHNOLOGY ISSUES

Integration of diverse transducers and different signal types into a Smart Transducer Module
Radio Frequency Transmission, Fiber Optic Links, Infrared Transmission
Digital Input/Output Interfaces
Continued progress in Smart Skins (demonstration phase only)
Continued advances in micro-machining of transducers
Standards yet to evolve for Surface Mount Technology

CANDIDATE PROGRAMS

Shuttle C
Manned Missions to Mars
Space Station Freedom
Lunar Base
Upgrade/Replacement of Orbiter Modular Auxiliary Data System (MADS) Components
Stand-Alone Instrumentation Systems

MAJOR ACCOMPLISHMENTS

Progress in Micro-Machined Transducers
Demonstration of Smart Skins
Surface Mount Technology and Hybrid Electronics
High Pressure Stand-Alone Pressure Measurement Device (HP-SAPMD)

SIGNIFICANT MILESTONES

Research and Technology Base
Define Interfaces and Hierarchy
Demonstration in Laboratory
Detailed Test Objectives and Integration into Future Programs

APPENDIX 2

Joe Zimmerman
Marshall Space Flight Center

STATS - ADVANCED SENSORS & INSTRUMENTATION

KEY CONTACTS

NASA	MSFC	W. T. Powers
NASA	MSFC	J. E. Zimmerman
NASA	LaRC	W. Nieberding
NASA	LaRC	G. Madzsar
NASA	SSC	G. Woods
AEDC		C. W. Darlington
Rocketdyne		S. Barkhoudarian
Aerojet		R. LaBotz
Pratt & Whitney		J. Baker
UTRC		R. Williams
NASA	KSC	W. Helms

STATS - ADVANCED SENSORS & INSTRUMENTATION

MAJOR MILESTONES

Optical Plume Anomaly Detector	08/87
Infrared Gas Thermometer	03/89
Ultrasonic Flowmeter	06/89
Vortex Shedding Flowmeter	02/89
Non-Intrusive Speed Sensor	11/87
Fiber Optic Raman Thermometer	06/88
Nozzle Exit Plane Velocity Sensor	11/88
Thin-Film Sensors	08/89

General

Research and development programs are being conducted for improvement of sensors used on present Space Transportation Systems, providing sensors for current engine requirements where no practical measurement techniques are commercially available, and to assure availability of measurement technology to meet future Space Transportation Avionics System requirements. Benefiting programs will include the Space Shuttle Elements (SSME and SRB), Advanced Launch Vehicle, Orbital Transfer Vehicles, and long-duration space flights or exploration program.

Earth-To-Orbit Propulsion Program

One group of research projects being conducted is under the Civil Space Transportation Initiative (CSTI) and specifically the Earth-To-Orbit (ETO) Chemical Propulsion program. The ETO program is a joint MSFC and LaRC effort with research projects being performed in-house and through outside contracts with other Government agencies, universities, and private industry. The emphasis of the ETO program is the continuing enhancement of knowledge, understanding, and design methodology applicable to the development of advanced Oxygen/Hydrogen and Oxygen/Hydrocarbon propulsion systems. Significant research activities in the ETO program are summarized in the following paragraphs.

An Optical Plume Anomaly Detector (OPAD) is being developed to view and analyze the SSME exhaust plume with the intent of obtaining information that would provide early indications of engine component degradation and/or precursors to a catastrophic engine failure. OPAD components include high resolution spectrometers and optical multi-channel analyzers. Testing of the OPAD during SSME engine firings at the Stennis Space Center (SSC) and at MSFC has been extremely successful and plans are being made to install ground-based OPAD systems at each test and launch facility. The potential of a flyable OPAD is also being investigated to provide input to a health monitoring system. An in-flight system could also provide information on normal engine component wear and possibly reduce the amount of disassembly and physical inspections of the engines after each flight.

Advanced cryogenic flowmeters are being developed for use on SSME class engines. Vortex shedding flowmeters have been designed and tested with promising results in some of the SSME ducts. Nonintrusive ultrasonic flowmeters are also scheduled for feasibility testing in the FY 90-91 time frame.

Other nonintrusive sensors under development for use on the SSME includes electromagnetic speed sensors for monitoring turbo pump speed, infrared hot gas temperature sensor for monitoring turbine exhaust temperatures, and a Raman backscatter thermometer for determination of temperature distribution within the pre-burners of the SSME. These sensors have successfully completed laboratory evaluation testing and are in the design phase for testing in an engine environment.

Solid-state and fiber optic based pressure sensors are being investigated for potential use on the SSME. These devices are being designed for direct mounting on cryogenic ducts to replace existing sensors which have to be off-mounted due to thermal sensitivity of the conditioning electronics.

Gaseous leak detection techniques are being investigated and developed for remote sensing of hydrogen leaks from space vehicle plumbing systems. Current sensing techniques are limited to point sensors which requires prior knowledge of the location of the leak or an extremely large number of sensors located around the vehicle to effectively quantify the leakage.

A nozzle exit plane measurement system is being developed for identification of species and flow velocity determination at the exit of the SSME nozzle. The system uses laser-induced flourescence to tag molecules in the flow stream for processing to determine specie concentrations and velocities. The system is being developed for combustion code validations and engine performance analysis.

Thin film sensors are being developed for deposition on turbine blades and other engine components which require minimally intrusive diagnostics. Film deposition processes have been developed for measurement of temperature and heat flux on SSME turbine blades. Initial testing of instrumented blades has been accomplished on the Turbine Blade Tester at MSFC with promising results.

Solid Propulsion Integrity Program

Another group of research projects under the CSTI program are included in the Solid Propulsion Integrity Program (SPIP). The instrumentation development task is a sub-element of a Nozzles Technology effort monitored by MSFC. Instrumentation research includes investigations and development of new or advanced measurement techniques for use on or in composite materials of solid rocket motor nozzles. Emphasis is on high temperature, high response sensors for the measurement of temperature, strain, pressure, and stress in the composite materials. Tasks include investigation of attachment techniques and operational capabilities to the 1100°C temperature range for strain, stress, and pressure sensors. Fiber optic techniques are being studied for these applications. Attachment techniques include both surface mounted and embedded sensors. Another type sensor under investigation is a recession gage to measure erosion of the throat material during a motor firing. Sensors developed under the SPIP program will be tested and evaluated in the solid rocket motor test beds at MSFC.

Space Station Freedom Related

Three significant development projects are being conducted with applications on long-duration manned space ventures. All are involved with monitoring the atmosphere within a habitable enclosure.

An advanced Tandem Mass Spectrometer is being developed for trace contaminant monitoring. This spectrometer will reduce the time required to obtain a readout of the contaminant present from 30 minutes to 5 minutes, giving near real-time warning of hazardous conditions. The development effort is in Phase II of a Small Business Innovative Research (SBIR) program.

Another Phase II SBIR is being supported for the development of a Trace Atmospheric Carbon Monoxide Sensor. The objective is to develop a compact, sensitive CO sensor which is species selective and has low power consumption. The sensor uses a nondispersive infrared technique.

A Hazardous Materials Monitor (HMM) system is also under investigation for monitoring 5 groups of contaminants which might be found in a space station module. The groups are: metallic vapors; metallic aerosols; organic solvent vapors; gases, fuels, and combustion products; and etchants. The HMM will be used to sense inadvertent leaks of hazardous substances from experiments on-board Space Station Freedom and provide early warning for the crew to take appropriate remedial or evasive action. There is presently no other such monitoring system planned for the space station.

APPENDIX 3

Rusty Morrison

Rocketdyne International

Advanced Sensor and Instrumentation development work at Rocketdyne and in the rocket engine world in general has been driven primarily by safety and maintenance considerations rather than control needs. The desire is to detect degradation in the engine in time to alter operation (shutdown or throttle back) to protect the crew and mission and/or diagnose condition, predict life, schedule maintenance, and support automation of ground operations. To these ends, studies dating back to 1980 have analyzed actual engine field operational recorded to determine historic degradation modes (example-89CA-079-41) and estimated current design and development information on current designs. These modes and the component most affected by them are summarized in table 89CA-079-42. Measurements have been identified at each stage of the degradation process and surveys of sensor technologies have been conducted to identify concepts with maximum payoff potential. Table 490-660A identifies the technologies currently under development for application to rocket engines.

Multi-disciplinary issues must be addressed in any sensor system concept. An integrated approach to system definition involves the engine system and component designers who define the measurants of interest and required data rates; the engine control system designer addressing functional distribution of processing, bus data rates, etc.; and the sensor design team itself which includes the sensor designer(s), the designer(s) of the part to which the sensor is mounted, associated stress, structural dynamics, thermal analysis, and the process physicist who relates the measurement of interest to what is recorded by the sensor. In the context of this integrated approach, smart sensors, in which the transducer itself outputs a digital data stream, optical sensors capable of easily integrating directly with fiberoptic data buses and tolerating extreme environments, and non-intrusive sensor technologies which don't penetrate pressure containers or interfere with the process being measured are current thrusts.

ADVANCED INSTRUMENTATION TECHNOLOGIES AND PROGRAMS

Summaries are given below of representative advanced instrumentation technologies under development for rocket engine applications. Research referred to includes that being performed by Rocketdyne Instrumentation personnel under IR&D, SSME Technology Test Bed, and Orbital Transfer Vehicle Engine tasks.

The general goal of these efforts is to improve mission safety, confidence, readiness, and life cycle costs. Corollary goals are to accelerate turnaround times and to help reduce the "standing army" associated with between flight inspection and qualification of reusable engines. In addition, nonintrusive and/or nonprotrusive technologies are being developed to reduce the hazard associated with conventional measurement technologies or to provide valuable diagnostic data currently unobtainable because of hostile engine environments.

Several technologies developed for space transportation may be adaptable to manufacturing applications (e.g. leak tests and weld inspections). One of the underaddressed applications of advanced instrumentation for space transportation in general is its role in manufacturing processes. Focusing on monitoring and inspection capabilities over the entire life cycle of the system, from the start of manufacturing and throughout the system operating life, would provide the greatest gains in reduced life cycle costs and improved mission readiness.

No fundamental cultural changes at NASA seem necessary to support development of these technologies: numerous programs are initiated to support this development. Nevertheless, improved communication and coordination would be helpful between the different NASA divisions, between NASA and other Government agencies, and between NASA and companies developing or potentially using these technologies. This will provide a better bridge between the development of these technologies and their application in transportation systems. In this regard, accelerated funding is called for to allow timely implementation of the most promising of these technologies.

Bearing Deflectometry

Description: A probe containing an optical fiber bundle is mounted in the engine with its tip in close proximity to the outside of a bearing race. Based on the intensity of light reflected from the race and back into the probe, minute deflections of the race surface are monitored at high frequency. This has proven in turbopump testbed applications to be a very sensitive indicator of bearing vibrations which can be correlated to bearing condition in real-time.

Programs: SSME Technology Testbed

Key Researchers: J. Collins and C. Martinez

Addressed Transportation Needs: Improved flight safety, accelerated turn-around times, disassembly for cause rather than schedule, reduced life cycle costs, and improved mission confidence.

Time for Implementation Readiness: ca 1991

Relationship between technology development and transportation system development for this topic: Provisions for incorporation of the fiber optic probe(s) should be included in the engine design process. An historical database should be developed to quantitatively correlate bearing deflectometer signatures to bearing conditions in operating engines.

Isotope Wear Analysis

Description: Prior to engine assembly, a selected component is endowed with a low level of radioactivity on a portion of its surface. After assembly, the level of radioactivity is monitored between firings with a detector/analyzer operating externally to the engine. The loss of radioactivity is correlated to mass loss at the component surface with a resolution on the order of micrograms. The determined mass loss can be used to calculate remaining life of the component accurately without requiring engine disassembly.

Key Researchers: J. Collins, M. Randall, and S. Barkhoudarian

Addressed Transportation Needs: Accelerated turn-around times, disassembly for cause rather than schedule, reduced life cycle costs, and improved mission confidence.

Time for Implementation Readiness: ca 1990

Relationship between technology development and transportation system development for this topic: Pre-irradiation of components requiring wear monitoring should be included as part of engine fabrication procedures. This will allow application of this nonintrusive technology.

Fiber Optic Turbine Blade Pyrometry

Description: A fiber optic probe is used to collect infrared thermal radiation from turbine blades as they rotate past the probe. This radiation is analyzed to determine temperature profiles of each blade in real-time. This information is used to identify small blade cracks which create hot spots, and other indicators of incipient blade failure.

Programs: SSME Technology Testbed, Reusable Rocket Engine Turbopump Health Monitoring Program

Key Researchers: J. Collins and M. Randall

Addressed Transportation Needs: Improved flight safety, accelerated turn-around times, disassembly for cause rather than schedule, reduced life cycle costs, and improved mission confidence.

Time for Implementation Readiness: ca 1992

Relationship between technology development and transportation system development for this topic: Provisions for incorporation of the fiber optic probe should be included in the engine design process. A historical database should be developed to quantitatively correlate

pyrometer signatures to blade conditions in operating rocket engines.

Between-Flight Optical Leak Detection

Description: During between-flight inspection, an engine or other component is pressurized with an inert infrared-absorbing gas. The engine is illuminated with infrared light and monitored with an infrared camera. An infrared image of the engine, with leaking gas appearing as dark clouds in the vicinity of the leak, is provided by the infrared camera. Leaks from large sections of the engine are thereby monitored simultaneously and rapidly with high sensitivity (down to 5×10^{-4} scim). This technology is substantially more amendable to automation than currently used techniques for leak location and quantification. This would make possible system leak inspection times on the order of a few minutes. Current programs: SSME Technology Testbed, Rocketdyne Advanced Instrumentation IR&D.

Key Researchers: R. Delcher, M. Randall, and J. Maram

Addressed Transportation Needs: Improved flight safety, accelerated turn-around times, disassembly for cause rather than schedule, reduced life cycle costs, and improved mission confidence.

Time for Implementation Readiness: ca 1990

Relationship between technology development and transportation system development for this topic: Qualification of an appropriate pressurant gas for optical leak checks should be part of the transportation system development.

In-flight (Propellant) Optical Leak Detection

Description: Optical methods are being developed for real-time detection, location, and quantification of propellant leaks in flight or in space. Among the methods being considered are light absorption/imaging techniques in the infrared or ultraviolet similar to the method described for between-flight leak detection. Other optical techniques, including Raman scattering, also show significant promise and are being investigated.

Key Researchers: R. Delcher, D. Gobeli, and J. Maram

Addressed Transportation Needs: Improved flight safety, accelerated turn-around times, disassembly for cause rather than schedule, reduced life cycle costs, and improved mission confidence.

Time for Implementation Readiness: ca 1993

Relationship between technology development and transportation system development for this topic: Provisions for optical accessibility to external engine components would improve the effectiveness of this technology.

Remote Plume Spectrometry

Description: Light from rocket engine plumes is monitored with remote, ground-based optics. The light is analyzed spectrometrically to detect and

measure the quantity of molecular and atomic constituents in the plume. Such measurements have been made at Rocketdyne and at SSC in over a hundred engine test firings. These measurements are valuable tools in characterizing and distinguishing nominal and anomalous engine conditions. Furthermore, measured levels of several key plume constituents can serve as effective indicators of anomalous component wear and provide an early indicator of potential engine failure. For example, calcium-based constituents are characteristic of plume spectra from rocket engines such as the SSME, corresponding to nominal bearing cage wear. Plume spectra recorded in engine tests resulting in bearing cage failure have indicated substantial rise in these calcium-based constituents up to hundreds of seconds before redline detection and shutdown. Early detection of anomalous wear in nickel-alloy and copper components has also been accomplished by this means. Such diagnostics strongly suggest themselves as tools for early detection and minimization of failure damage.

Key Researchers: L. Wyett, J. Reinert, and D. Gobeli

Addressed Transportation Needs: Engine characterization, improved flight safety, accelerated turn-around times, disassembly for cause rather than schedule, reduced life cycle costs, and improved mission confidence.

Facilities in Use: Rocketdyne Advanced Instrumentation Laboratory, Santa Susana Field Laboratories, and Stennis Space Center

Time for Implementation Readiness: ca 1991

Relationship between technology development and transportation system development for this topic: Provisions for optical accessibility to external engine components would improve the effectiveness of this technology.

Ultrasonic Flowmetry

Description: An ultrasonic flowmeter is used as a nonintrusive means to measure propellant flow. A pair of ultrasonic transducers are mounted on a propellant duct. Ultrasonic signals are transmitted and received between the two transducers. The propellant flow velocity is determined by the frequency shift in the ultrasonic signals, in a calculation independent of propellant density and temperature. This flowmeter is designed to replace intrusive turbine flowmeters conventionally used in rocket engines. In the SSME Technology Testbed program, the ultrasonic flowmeter is being evaluated to replace the oxidizer flowmeter which was deemed unacceptable for the SSME and removed because of its intrusiveness.

Key Researchers: B. Szemenyei and S. Barkhoudarian

Addressed Transportation Needs: Engine characterization and improved flight safety.

Time for Implementation Readiness: ca 1991

Relationship between technology development and transportation system development for this topic: Provisions for mounting the ultrasonic transducers should be included in the selected duct design.

Nonintrusive Speed Sensing

Description: An externally mounted, nonintrusive sensor is used to measure turbopump shaft speed. Measurements are made by detection of fluctuations in magnetic field at the sensor caused by the periodic passage of permanent magnets embedded in the turbo pump speed nut. This technology has been developed to replace the intrusive magnetic speed sensor formerly used on the SSME oxidizer turbo pump.

Programs: None currently funded (formerly SSME Technology Testbed)

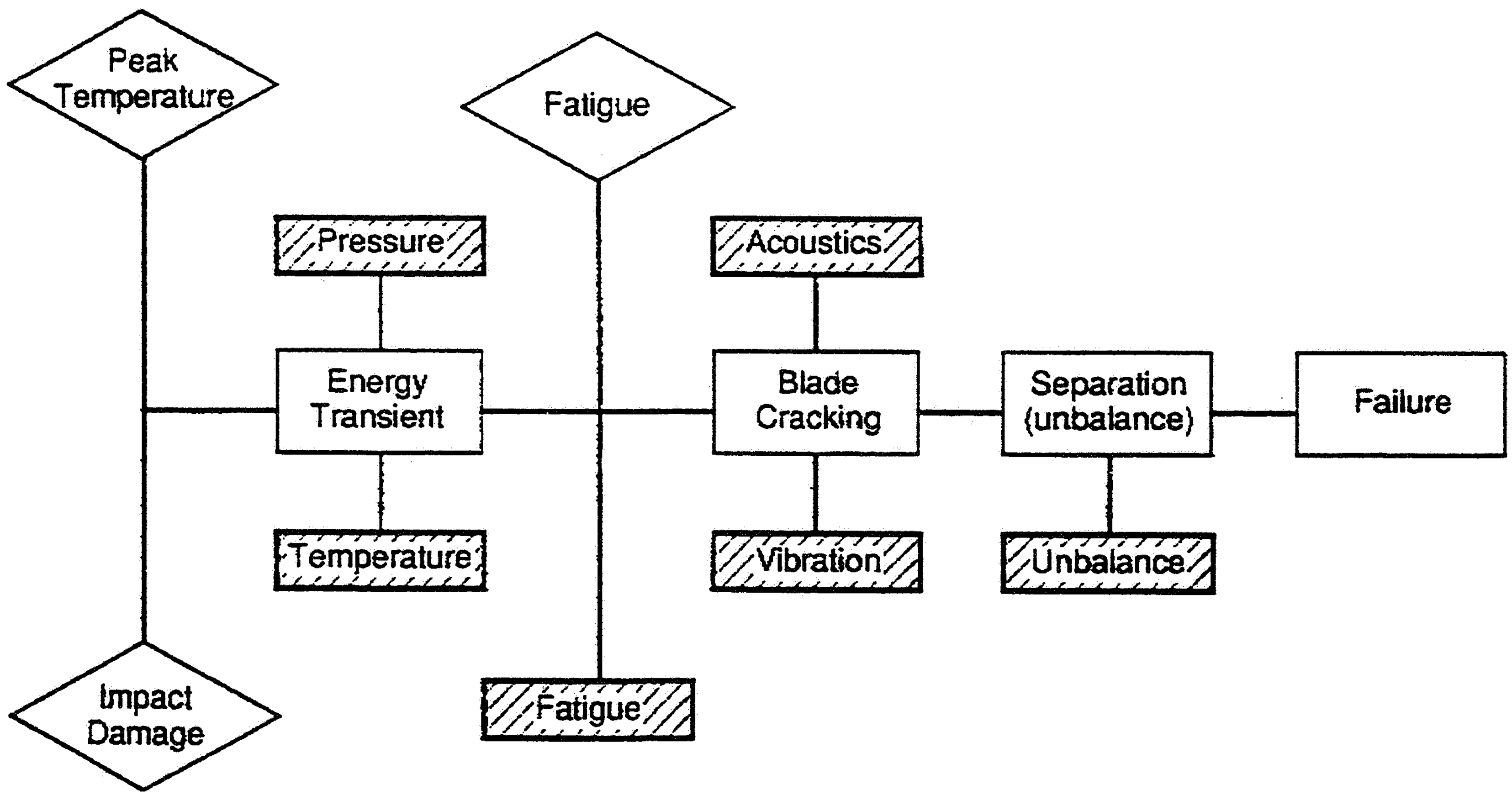
Key Researchers: L. Wyett, J. Reinert, and S. Barkhoudarian

Addressed Transportation Needs: Improved flight safety and improved mission confidence.

Time for Implementation Readiness: ca 1991

Relationship between technology development and transportation system development for this topic: In vehicles where this technology is to be used, provisions for incorporation of the magnets into the rotating assembly should be included in the engine design process.

IDENTIFYING FAILURE MODE SIGNATURES
Turbine Blade Failure



Rockwell International
Rocketdyne Division

FAILURE ANALYSIS

Failure Mode	Critical Components
Wear/erosion	Ball bearings, blades, injectors, posts, seals, seats, impellers
Fatigue	Blades, injectors, posts, bellows
Cracks	Blades, injectors, posts, bellows, welds, brazes
Leaks	Joints, welds, cracks
Leaks	Rotary seals, valve seats
Binding	Ball bearings
Spalling	Ball bearings
Blockage	Tubes
Thermal cycling	Blades
Foreign material	Combustion devices

Rockwell International
Rocketdyne Division

DIRECT CONDITION-MONITORING TECHNOLOGY PACKAGE

FAILURE MODE	CRITICAL COMPONENTS	BETWEEN FLIGHT			COAST OFF			IN FLIGHT		
TECHNOLOGY		ISOTOPE	HOLO-GRAPHIC	PYROM-ETER	EXO-ELECTRON	ACOUSTO-OPTICAL	TORQUE-METER	PYROM-ETER	SPECTROM-ETER	DEFLEC-TOMETER
WEAR/ EROSION	BALL BEARING, BLADE, INJECTOR, POST, SEAL, SEAT, IMPELLER, LABY	X								
LEAKS	JOINT, WELD, CRACK		X							
BLOCKAGE	TUBE			X						
FATIGUE	BLADE, INJECTOR, POST, BELLOWS				X					
CRACKS/ DELAMINATION	BLADE, INJECTOR, POST, HOUSING, WELD, BRAZE, DUCT					X				
BINDING	SEAL, BEARING, LABY						X			
THERMAL STRESS	BLADE							X		
LEAK	SEAL, LABYRINTH								X	
FOREIGN MATERIAL	PLUME								X	
SPALLING	BALL BEARING									X
AVAIL-ABILITY		C	P	C	P	P	P	C	P	C

C = COMMERCIAL, P = PROPRIETARY

490-660A

Rockwell International
Rocketdyne Division

729

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PRESENTATION 3.2.4

N91-17042

FAULT DETECTION AND FAULT MANAGEMENT

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FLIGHT ELEMENTS
FAULT DETECTION AND FAULT MANAGEMENT

WHITE PAPER

H. Lum, A. Patterson-Hine, J. T. Edge, D. Lawler
November 17, 1989

Background

Implementation of high-performance on-board intelligent computational systems is required to meet the requirements envisioned for NASA's current missions and the missions projected for the year 2000 era. Intelligent computational systems must be capable of: integrating, interpreting, and understanding sensor input information; correlating that information to the "world model" stored within its data base and understanding the differences, if any; defining, verifying, and validating a command sequence to merge the "external world" with the "internal world model"; and controlling the vehicle and/or platform to meet the scientific and engineering mission objectives. Critical to the implementation of such a system is an evolutionary approach taken to establish the baseline infrastructure for a real-time fault detection and fault management/reconfiguration system; the computational requirements for both ground mission operations and in-flight monitoring and operations will be highly dependent on the use of parallel and distributed computing in a fault-tolerant environment not totally dictated by the traditional implementation of triple redundancy. Decreases in mission operations costs while, at the same time, preserving the safety and reliability of flight missions, require a new and evolutionary approach to fault detection and fault management especially with the development and implementation of expert systems for system monitoring and advise. Currently, Mission Operations are left on their own to reverse-engineer the system designs to determine the consequences of failures on systems and functions, which involves a labor-intensive operation for both the design analysis and the mission operations support. Even the use of expert systems to automate failure analysis will not solve the problem of converting the systems schematics to the representation required by expert systems, nor will it provide the assurance that the software has been properly validated for mission critical use. The analysis of complex systems utilizing advanced automation and robotics must include an analysis of the software required by these systems as well as the hardware architecture. Techniques for modeling hardware systems and components need to be extended to represent the behavior of the software and to characterize the hardware/software interfaces. Traditional hardware fault management strategies such as hierarchical failure containment must also be applied to software components and addressed from an overall system fault management concept.

Concept

Fault management for an intelligent computational system must be developed using a "top-down" integrated engineering approach. Previous fault tolerant systems have been developed from a "bottom-up" approach, i.e., emphasizing the architecture required for a fault tolerant system rather than integrating the architecture with the overall mission requirements including the spacecraft design, ground and in-flight mission operations, and the design knowledge obtained from conceptual design through simulation, tests, integration, and flight operations. The proposed approach includes integrating the overall environment involving sensors and their as-

sociated data; design knowledge capture; operations; fault detection, identification, and reconfiguration; testability; causal models including digraph matrix analysis; and, overall performance impacts on the hardware and software architecture. Finally, the overall concept will be evaluated in testbeds simulating an operational environment to demonstrate technology readiness/feasibility for user transfer, establish user confidence in the technology , and validate the hardware/software architecture including the cost models for project implementation.

Objectives

Implementation of the concept to achieve a real-time intelligent fault detection and management system will be accomplished via the implementation of several major objectives which constitute the elements of the basic system infrastructure. These objectives are as follows:

a. Development of fault tolerant/FDIR requirements and specifications from a systems level which will carry through from conceptual design through implementation and mission operations. This element includes design data capture and acquisition throughout the life cycle of the project/mission. Figure 1, FT/RM Analysis Environment represents a realistic conceptual approach which will comply with the requirements of this objective.

b. Implementation of monitoring, diagnosis, and reconfiguration at all system levels providing the capability for unambiguous isolation of failures and integration of all systems aspects with mission maintenance support and operations.

c. Optimize system operations to manage degraded system performance through "top-down" system integration of all interacting elements with highest priority given to system availability through reconfiguration of hardware, software, and communications data networks, protocols, and interfaces.

d. Lower development and operations costs through the implementation of an intelligent real-time fault detection and fault management system including the development of an unified information management system (UNIS). UNIS will provide the capability for users to access the database at all levels independent of the skill level of the user thereby allowing real-time planning and scheduling consistent with program changes and deviations. Figure 2, FT/RM Analysis Process in the Space Station Program, is an example of an UNIS-type implementation to meet this objective.

Current Research Activities and Milestones

The proposed effort for Fault Detection and Fault Management will leverage current on-going activities currently being sponsored by the Office of Space Station Freedom, the Defense Advanced Research Projects Agency (DARPA), and the Office of Naval Research (ONR). As a result, the required technology development program to meet the proposed objectives will "inherit" the underlying basic research and development and will represent a cost-effective program. In addition, Space Station Freedom is already addressing some of the technology elements in its Advanced Technology Development Program and these efforts can also be applied to the development of the basic infrastructure of the Intelligent Fault Detection and Fault Management System using data obtained from existing Space Station testbeds and the Space Shuttle Program.

Early milestones which can be achieved are as follows:

CY-90: Review technology and investigate/define leveraging opportunities; define concept and develop integrated program technology development and integration plan

CY-91: Complete detailed definition of the integrated program plan and implementation of the supporting R & D technology base

CY-92: Test and evaluation of the integrated design strategies through simulations and testbed demonstrations. A proposed testbed demonstration is described below:

System concepts for software reliability and fault management will be validated using the advanced automated Space Station Freedom's Thermal Control System (TCS) jointly developed by ARC and JSC. Rapid prototyping capabilities and simulations will be conducted on ARC's TCS Research Testbed and system verification and validation will be conducted on JSC's TCS Testbed simulating the operational environment. System analysis will include both hardware and software. Techniques for modeling hardware systems will be extended to represent the behavior of the software and to characterize the hardware and software interfaces. Traditional hardware fault management strategies such as hierarchical failure containment will be applied to software components. The end product will be the demonstration of a fully automated, real-time fault management and control system utilizing advanced automation technologies and a system causal model for developing the criteria and evaluation of potential systems for implementation in a flight and/or operational environment. This demonstration will be a joint effort between ARC and JSC and will extend and leverage the original TCS effort sponsored jointly by OAST and OSS under the Systems Autonomy Demonstration Project (SADP) effort.

CY-93: Proof-of-Concept demonstration in an operational environment and optimization of the systems requirements document

CY-94 and beyond: Optimization of the hardware and software architectures to correct identified system design deficiencies, if any, and improve run-time performance. Initiate validation procedures for technology to be transferred to the user.

Key Researchers and Organizations

Current key researchers for the proposed effort are as follows:

Ames Research Center • : Dr. Ann Patterson-Hine (Point of Contact)
Dr. Henry Lum

Johnson Space Center • : J. T. Edge (Point of Contact)
Dennis Lawler

Langley Research Center: Chuck Meissner (Point of Contact)

Marshall Space Flight Center: David Weeks (Point of Contact)

• Major participants at the present time.

Note: The research and development collaboration for this effort will also utilize the on-going collaborative efforts with industry and academia. Figure 3 shows the collaborative research team which currently exists at Ames and can be leveraged to support the program.

Facilities

Key facilities are identified below and represent existing facilities which may be augmented to support the proposed effort:

Ames Research Center: Advanced Architectures Testbed, ALS/UNIS Testbed, and Space Station TCS Research Testbed. Figure 4 is an example of an existing testbed.

Johnson Space Center: Various Space Station and Space Shuttle Testbeds

Marshall Space Flight Center: SSM/PMAD and ECLSS Testbeds

No new facilities are required for this effort.

Candidate Benefiting Programs

The programs which will benefit from this effort include Space Shuttle, Space Station Freedom, NASA/AF Advanced Launch Systems (ALS), and the Lunar/Mars Missions. It is expected that Space Shuttle will be an early benefactor and the technologies transferred to the Space Shuttle environment will serve as the basic infrastructure for Space Station Freedom which will then be augmented to provide the additional required capabilities.

Major system needs which will be satisfied by this effort will be a decrease in the long-term mission operations costs through the development of a robust, intelligent fault detection and management system, higher quality decisions rendered during periods of uncertainty, and preservation of the "corporate knowledge" for long-life missions/projects. "Short-term" savings are not expected due to "up-front" implementation costs although efficiencies in personnel utilization for ground mission operations can be anticipated.

Technology Issues/Holes

Major technology issues/holes are as follows:

a. Validation methodologies for integrated knowledge-based systems (KBS) - Verification and validation (V&V) techniques are not tried (proven beyond doubt) and integrated for knowledge-based systems, i.e., systems that integrate both algorithmic and heuristic information. Validation processes are required before knowledge-based systems (also known as expert systems, intelligent systems, autonomous systems, and/or smart systems) will be incorporated into flight elements and in-line ground mission operations. Technical issues include: integration of validation processes; risk level permitted; applicable functional uses, i.e., critical and/or non-critical functions; languages; and validated software development tools.

b. Advanced integrated space-qualified multiprocessing architectures for intelligent fault detection, management, and control systems - Projected space-qualified architectures and processors do not address the hardware and software issues associated with highly automated fault

detection and management systems. This problem is increased when parallel processors, distributed processors, and knowledge-based systems are integrated into a heterogeneous computing environment. Issues include adaptive operating systems, languages; dynamic memory management and reallocation; network management; dynamic database management and consistency (truth maintenance); and validated on-chip testability functions.

c. Realistic causal model as the basis for automated fault detection, management, and control systems and general systems engineering analyses - A realistic causal model does not exist for the implementation of an automated (knowledge-based) fault detection, management, and control system and systems analysis. As a result, project managers cannot evaluate the effectiveness of automated systems. The automated Thermal Control System, jointly developed by Ames Research Center and Johnson Space Center, represents a start in the development of a realistic causal model. The effort has to be extended to reflect the entire system (only 25% of the system was automated for the Space Station Freedom engineering demonstration). Such a "core" model must support, in a principle manner, a broad range of systems engineering analysis such as: cost analysis, risk analysis, OPS analysis, FMEA, testability analysis, integration analysis, and automation analysis. (This concept is shown in Figure 1.)

d. Development and Maintenance of a reliability database - Reliability data is historically not available for NASA programs in a timely manner and is constrained by procurement procedures. Hence, NASA must develop the required databases using small samples which can be scalable.

e. Development of a theoretical foundation for systems engineering and integration - Only ad hoc techniques and techniques applicable to isolated systems and functions are currently available. A accepted general theory is not available to support the broad integrated analysis for the launch system as an entire system throughout the system lifecycle. Specific quantitative metrics are required for system engineers to accurately judge the consistency and completeness with which a current design meets systems requirements and constraints.

Recommended Cultural Changes

The following NASA cultural changes are recommended to facilitate this technology development:

a. Acceptance of fault detection, fault management, and control as an INTEGRATED SYSTEM ENGINEERING DISCIPLINE and not as a R&QA requirement, i.e., use a top-down integrated engineering approach.

b. Acceptance of fault management and control as a complementary approach to the classical (traditional) fault tolerant approach (triple redundancy). Maximize system availability with minimum system degradation.

c. Relaxation of validation requirements for knowledge-based systems, i.e., determination of an acceptable level of risk for systems incorporating heuristic (non-deterministic) information.

d. Incorporate systems engineering and integration as a driving force/organization in large complex system developments. Currently this discipline shares equal levels of design influence with areas such as OPS. This is inappropriate for driving the required functionality into the design while meeting other design constraints such as cost and fault tolerance.

FT/RM ANALYSIS ENVIRONMENT

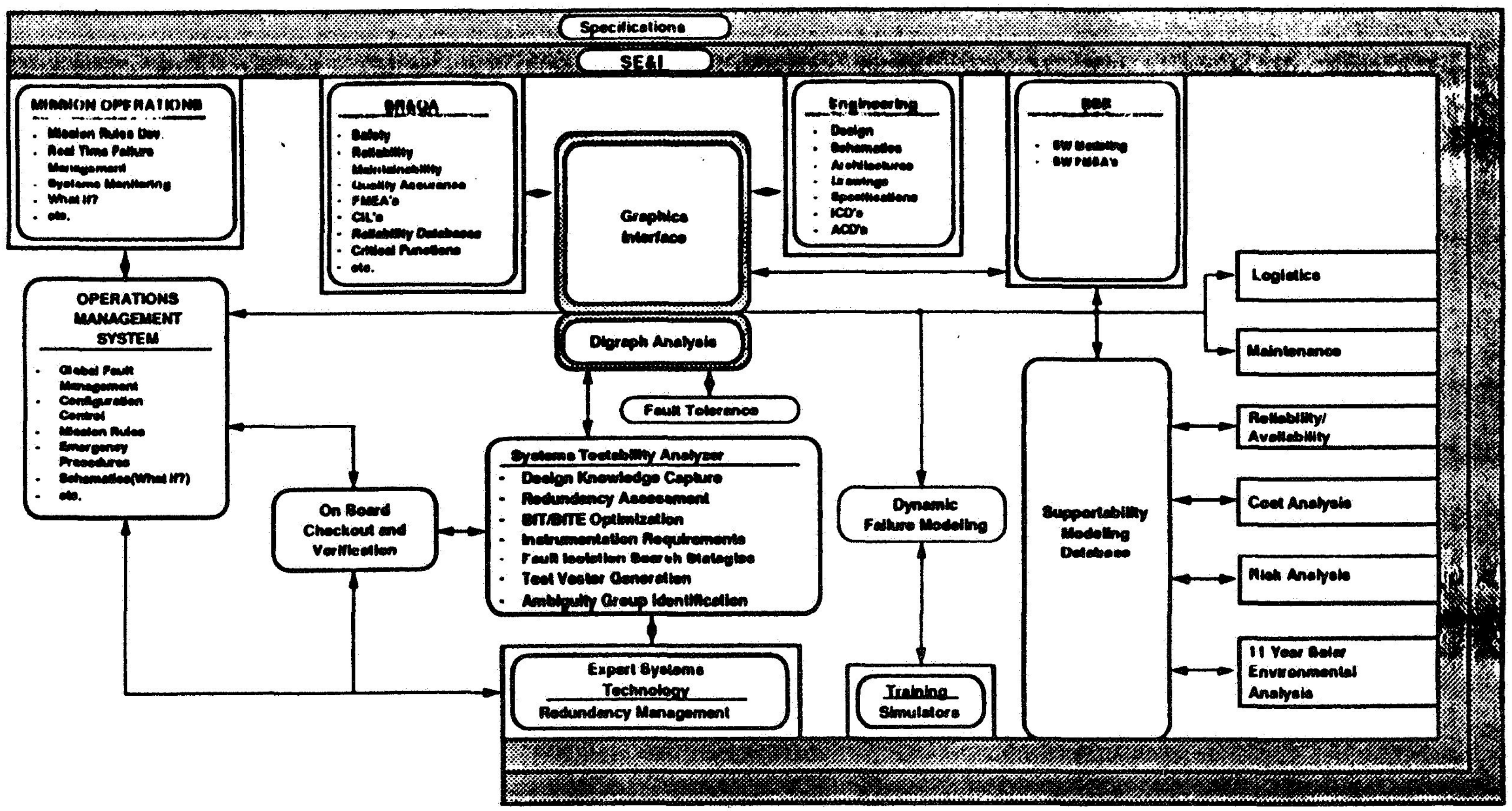

Figure 1

FT/RM ANALYSIS PROCESS IN THE SPACE STATION PROGRAM

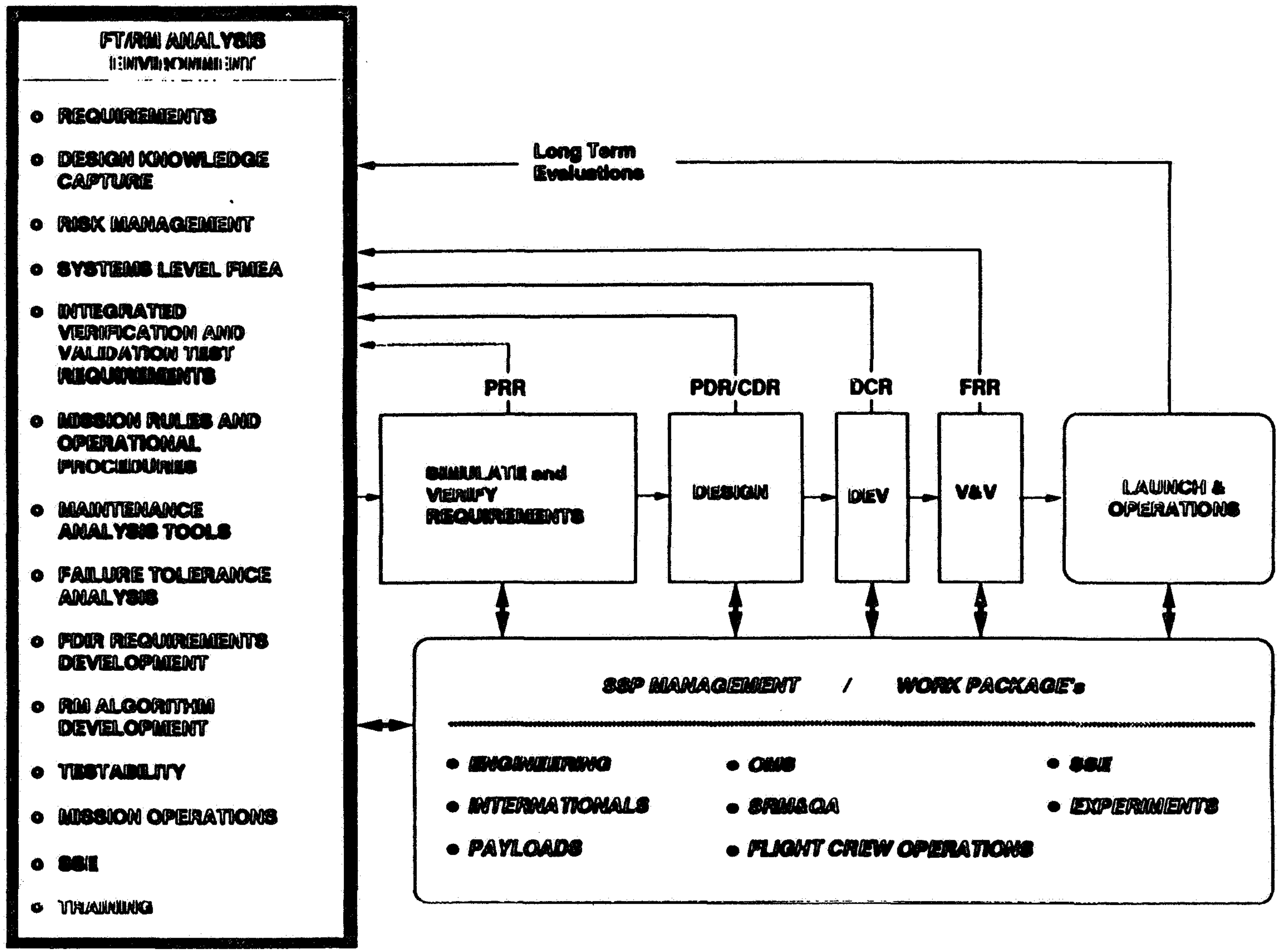

Figure 2

AMES COLLABORATIVE AI AND COMPUTER ARCHITECTURES RESEARCH TEAM

INFORMATION SCIENCES DIVISION (RI)

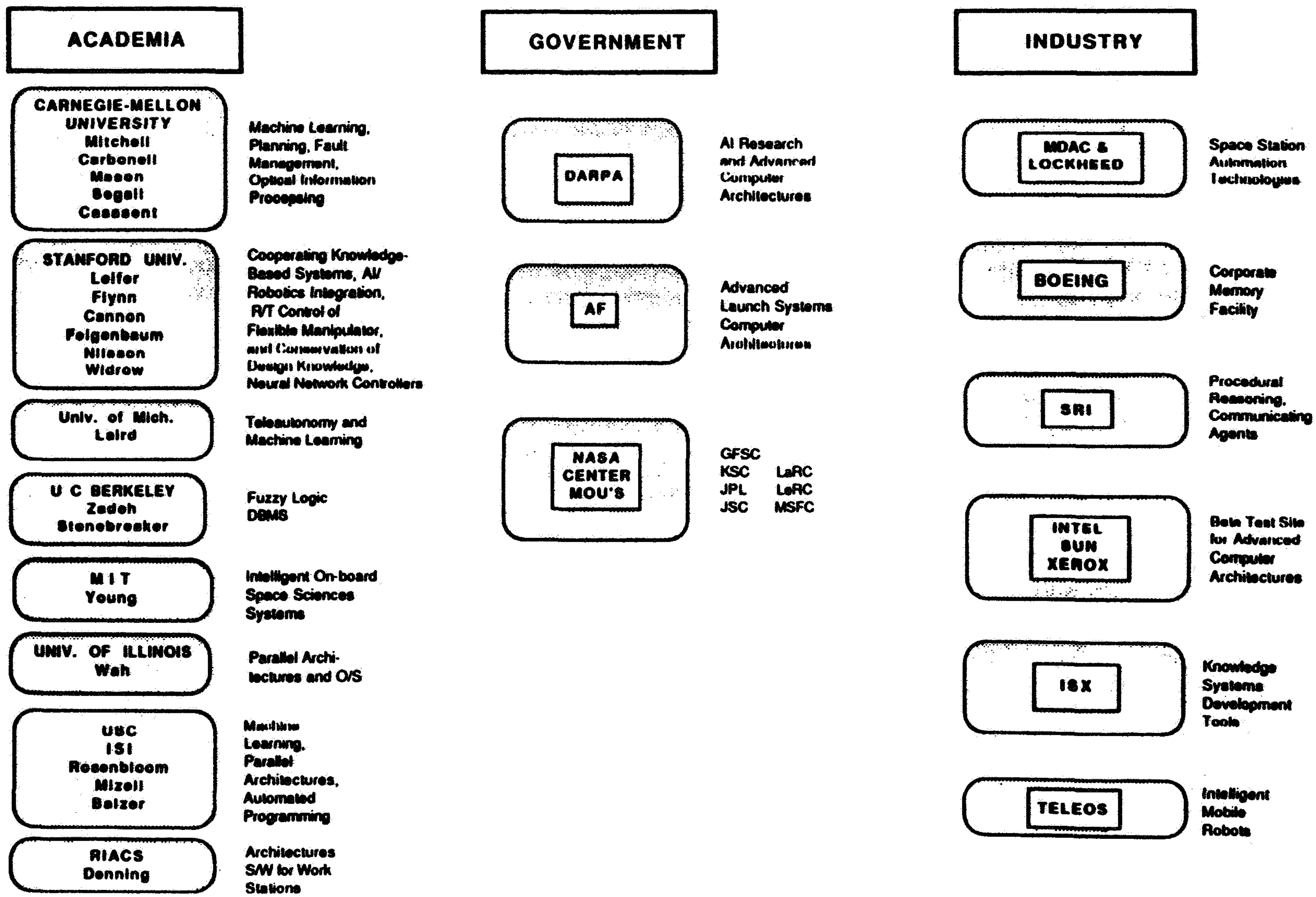

Figure 3

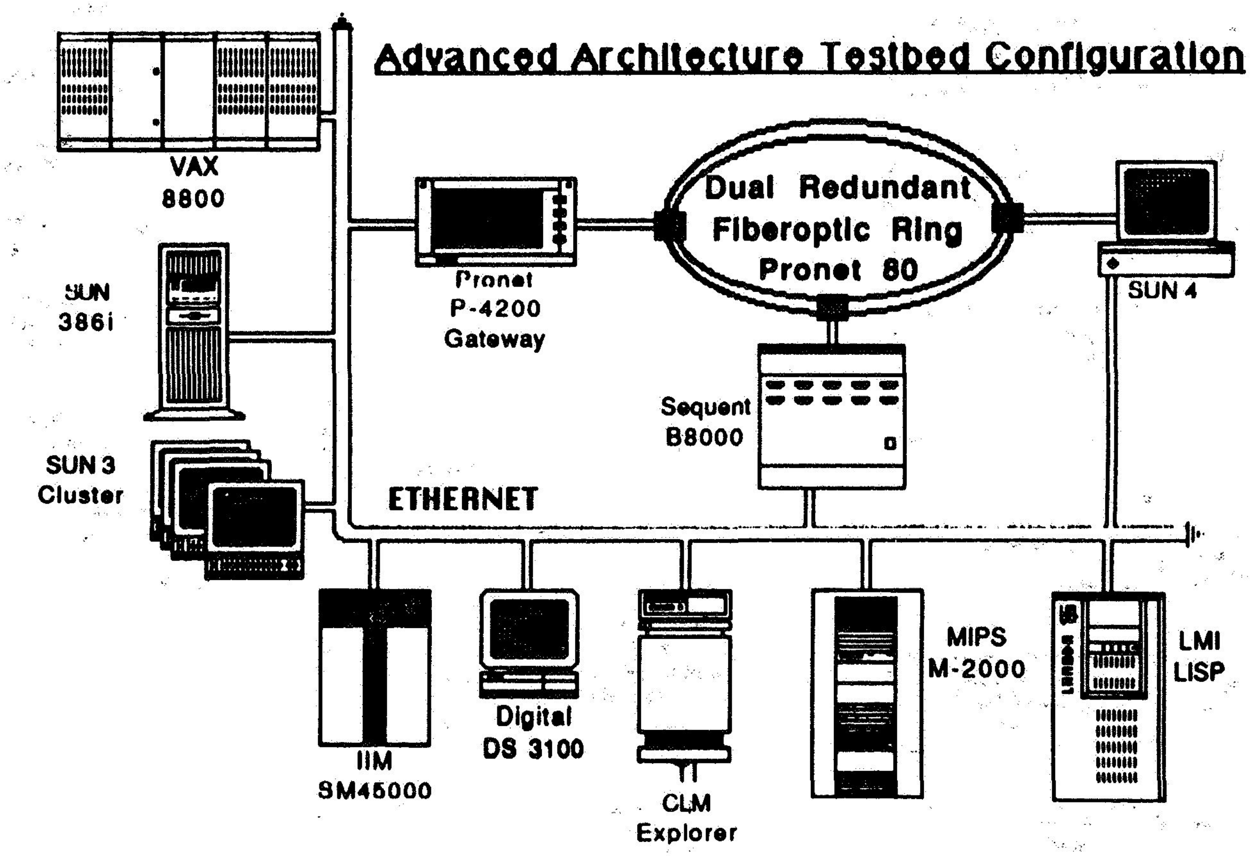
Advanced Architecture Testbed Configuration
VAX
8800
SUN
386i
SUN 3
Cluster
Pronet
P-4200
Gateway
Dual Redundant
Fiberoptic Ring
Pronet 80
SUN 4
Sequent
B8000
ETHERNET
IIM
SM45000
Digital
DS 3100
CLM
Explorer
MIPS
M-2000
LMI
LISP

Figure 4

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PRESENTATION 3.2.5

N91-17043

ADVANCE ELECTRICAL POWER, DISTRIBUTION AND CONTROL

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ADVANCED ELECTRICAL POWER, DISTRIBUTION AND CONTROL FOR THE SPACE TRANSPORTATION SYSTEM

WHTE PAPER

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NOVEMBER, 1989

BACKGROUND

MAJOR OBJECTIVES

SIGNIFICANT RESEARCH ACTIVITIES

KEY RESEARCHERS AND FACILITIES

The key people involved in various activities supporting the electrical actuation and power system work and the major facilities are listed in the quad charts.

TECHNOLOGY ISSUES AND MAJOR ACCOMPLISHMENTS

The quad charts list the key issues and major accomplishments to date that will impact the Space Transportation System.

CONCLUSIONS

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
FLIGHT ELEMENTS
ADVANCED ELECTRICAL POWER, DISTRIBUTION AND CONTROL

NOVEMBER 1989

TECHNOLOGY ISSUES:

END-TO-END EPS MANAGEMENT WITH FAULT LIMITING, RECOVERY AND FAIL SAFE/FAIL OPERATIONAL RECONFIGURATION

DISTRIBUTED vs. DEDICATED PMAD FOR REDUNDANCY, RELIABILITY, OPERABILITY

BITE INTEGRATED INTO DESIGN AT MANUFACTURE

ASA: DDT&E FOR ELECTRICAL ACTUATORS RETROFIT BY ORBITER STRUCTUAL INSPECTION DATE

CANDIDATE PROGRAMS:

ADVANCED LAUNCH SYSTEM

ASSURED SHUTTLE AVAILABILITY

CIVIL AERO - POWER-BY-WIRE/FLY-BY-LIGHT

LUNAR/MARS INITIATIVE

AF/WRDC - MORE ELECTRIC AIRPLANE - RETROFIT F-16

DAVID TAYLOR SHIP R&DC - ELECTRONIC NAVY

MAJOR ACCOMPLISHMENTS:

- DEMONSTRATED MULTI-REDUNDANT, FAULT TOLERANT, MICROPROCESSOR CONTROLLED SSF 20 kHz ELECTRICAL POWER DISTRIBUTION SYSTEM
- DEMONSTRATED VARIABLE SPEED DRIVES TO 200 HP, ELECTRICAL ACTUATORS TO 25 HP/DESIGNS TO 75 HP

SIGNIFICANT MILESTONES:

1990 R&T BASE - COMPS, POWER SEMI'S

1991 1992 ADV. DEV. - SSF, ALS

1995 DDT&E

▽ LEV. 5 MATURITY △ NSTS NEED DATE △ LUNAR/MARS NEED DATE

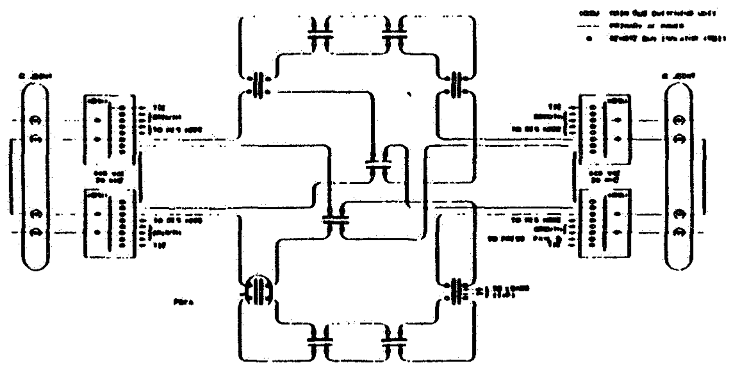
VALIDATION NEAR COMPLETE:

- ADVANCED HIGH POWER PMAD CONCEPTS APPLICABLE TO CANDIDATE PROGRAMS
- ADVANCED MOTOR CONTROL ENABLING INDUCTION MOTOR EXPLOITATION FOR LUNAR/MARS VEHICLES

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
FLIGHT ELEMENTS
ADVANCED ELECTRICAL POWER, DISTRIBUTION AND CONTROL

NOVEMBER 1989

ADVANCED ELECTRICAL POWER, DISTRIBUTION AND CONTROL



SPACE STATION RING DISTRIBUTION SYSTEM (EXTERNAL LOAD AREAS ONLY)

MAJOR OBJECTIVES:

- REDUCE COSTS TO LEO, LUNAR/MARS SURFACE
- REDUCE WEIGHT
- INCREASE AVAILABLE POWER/ENERGY
- IMPROVED REDUNDANCY MANAGEMENT
- IMPROVED POWER QUALITY, USER AVAILABILITY
- FAULT TOLERANT, INTEGRATED BITE

KEY CONTACTS:

H. BRANDHORST/LeRC
I. HANSEN/LeRC
J. MILDICE/GDSS
J. BIESS/TRW
R. BECHTEL/MSFC

FACILITIES:

LeRC POWER TECHNOLOGY TESTBED

MAJOR MILESTONES (1990-1995):

SPACE STATION FREEDOM

1990 ADV. DEV. TEST BED DEMOS

ADVANCED LAUNCH SYSTEM

1990 — 1992 ADV. DEV. DEMO OF IEPS

CIVIL AERO-FBL/PBW

1991 — 1993 (TECH. VALID.) | 1995 (DDT&E) | 1996 (FLIGHT DEMO.)

LUNAR/MARS INITIATIVE

1992 — 1995

STUDIES ---------- ADV. DEV. PROG.

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TECHNICAL ISSUES

Electrical system reliability is in reality the probability of suitable electrical power being available to user loads. Long term reliability is achieved by parallel redundant elements in a single distribution block consisting of a source, storage (if required), and a distribution system all under active control and management. Uninterruptible, or secure power, for critical loads may be implemented by an additional block, or blocks, depending upon the requirements. Within a single block, fault limiting, fault isolation, and fault recovery through reconfiguration are implemented to maintain as much post fault capability as possible. This capability (fault tolerance) involves status sensing, intelligence, current limiting, and active switching. When all available technologies are fully reviewed, it becomes obvious that these requirements may be much more easily met by utilizing a distributed, alternating current (AC) system. The system physics, the system fault recoverability, and the overwhelming terrestrial experience support this conclusion. Given an AC system several engineering decisions remain as regards the distribution voltage, waveform, and frequencies. While each specific application must be evaluated, point designs and operating experience to date support the selection of ultrasonic, sinusoidal power systems operated at the highest voltage appropriate to the situation.

SIGNIFICANT RESEARCH ACTIVITIES

As the accompanying quad-charts show there are six candidate Government supported programs working on relevant technologies

with significant applications for electric actuators and integrated power distribution and control systems. The programs are listed below with a brief explanation and noteworthy technology.

ADVANCED LAUNCH SYSTEM

Four Advanced Development Tasks are directed to the development and demonstration of electrical actuators and electrical power systems for the proposed new family of heavy lift launch vehicles. Actuators for thrust vector control (TVC), fuel valves and others with ratings in the ranges of 5, 70, and 75 Hp are being developed with subsystem demonstrations scheduled before March 1992. Figure 2 shows the ALS EMA system demonstration activities and milestones. An additional task is being conducted by LeRC to provide advanced motor drive technology, motor designs, BITE concepts, and transfer the technologies directly to all the prime contractors. The 5 Hp drive has already been demonstrated, the 25 Hp drive and actuator will be tested in March 1990, and the 30 and 40 Hp actuators will be ready by early 1991.

The power semiconductors necessary to meet the peak horsepower ratings are now available and improved MOSFET Controlled Thyristors (MCT) will be available in six months. Circuit topologies and system architectures are available which meet required redundancy, fault tolerance and fault containment. An appropriate power control and distribution system integrated with an avionic and propulsion system will be demonstrated in 1992.

ASSURED SHUTTLE AVAILABILITY

A preliminary ASA study by Rockwell Downey concluded that electric actuation was feasible, the technology was ready, and a five to six year schedule was reasonable to accomplish the DDT&E required to retrofit electric actuators into the existing Shuttle Orbiters. JSC is also supporting an analysis of ten Shuttle subsystem processing costs and turn-around flows. The EMA system is planned as the vanguard item to trade against the existing hydraulic systems.

CIVIL TRANSPORT: POWER-BY-WIRE/FLY-BY-LIGHT

This program is a planned new initiative for FY91. The power-by-wire (PBW) portion of the program includes an all electric secondary electrical power system that includes electrical actuators, embedded engine generators, fixed bleed turbine engines, advanced power distribution architectures, BITE and electric driven environmental control systems. Studies at LeRC on a 767 class aircraft have shown a potential weight and fuel savings of nearly 10% by using the PBW approach. Plans in this initiative include development, fabrication, testing and flight evaluation of engineering prototypes by 1996.

LUNAR/MARS INITIATIVE

Preliminary assessments have been made by the agency for a report to the Space Council. Several scenarios, require relatively high power, long duration, automated, distribution systems. Surface rovers and mining vehicles will require reliable, power efficient actuation and variable speed motor drive systems.

AF/WRDC - MORE ELECTRIC AIRPLANE - RETROFIT OF F-16

Wright Research and Development Center under their More Electric

Airplane Program has contracted General Dynamics of Fort Worth, TX to do a trade study of the F-16 resulting in development costs, risks, and payoffs expected by replacing hydraulics with electrical actuation systems. Performance, operability, maintainability and recurring cost reductions are the main drivers. This work is jointly sponsored by NASA LeRC.

DAVID TAYLOR SHIP R&D CENTER - ELECTRONIC NAVY

The US Navy has begun a massive joint program with DARPA to develop technologies that will enable all electric variable speed drivers of both the main propulsion engines and new weapon systems. This will require megawatts of power generation and distribution capability with new types of electronic control and motor drives. They plan to demonstrate a 200 Hp drive by the end of 1991 and work toward a capability to drive 3600 Hp induction motors. Motor drives and the required very high power MCTs and associated electronic components are already under intensive development and planned qualification. New programs include development of electric actuators to replace many hydraulic actuation systems.

BUILT-IN TEST EQUIPMENT (BITE)

The maximum advantage of BITE will be realized when the capability is introduced into the equipment at manufacture. The BITE may then be calibrated and compared during all following acceptance testing.

As presently conceived, BITE will support system checkout and verification for ALS, and eventually provide the system status information allowing automatic control of long duration power

requirements. When considering large multinode power distribution systems, the advantage of pushing intelligence deeply into the system cannot be minimized. With centralized intelligence software complexity, and its attendant verification problems, grows much more rapidly than the system does. However, as intelligence is pushed down, the problem approaches that of the verification of replicated simple instructions. Finally, it is intended to use BITE to provide the physical foundation, and experience base for the eventual incorporation of trend analysis, failure prediction, and expert systems in general.

BACKGROUND

For over a decade NASA LeRC has been evaluating, and defining power components and system characteristics as part of our OAST charter. This work provided a foundation for the Advanced Aircraft Secondary Power System Study in 1985 which concluded that a 20 kHz AC system had great advantages particularly when multikilowatt, multiply redundant, distribution was involved. This study also recognized the advantage of high frequency power for motor operation was proposed. In the intervening years, the technology has been reduced to practice and evaluate with several full power testbeds. The baseline 20 kHz power distribution for Space Station is shown in the diagram. The system comprised two independantly powered feeders (left and right) similar to conventional aircraft practice. All loads had current limiting remote power controllers (RPC's) and could draw power from either feeder subject to power management.

Differential protection was provided between nodes to monitor

soft and hard faults. In this system the RPC's were programmable for: off, on, trip level, monitors indicated switch status, the current flowing, and produced a flag when over current trips occurred. Similar instrumentation, but no current limiting or tripping, was provided by the node switches or remote bus isolators (RBI's). This system was assembled at Lewis and operated with total success for over a year.

It is the confidence gained from the Space Station Testbeds, advanced components, and operating experinece that forms the foundation for advanced electrical power, distribution, and control. These advances in power control and newly demonstrated capabilities for control of a larger class of inherently rugged, induction motors using pulse-population-modulation with field-oriented control from a high frequency source makes this approach even more attractive. For example, selective steering of high frequency, small energy pulses and switching at zero crossing significantly reduces the size and weight of the electronics while practically eliminating EMI/EMC effects.

CONCLUSIONS

High frequency power distribution and management is a technology-ready state of development. As such, a system employs the fewest power conversion steps, and employs zero current switching for those steps. It results in the most efficiency, and lowest total parts system count when equivalent systems are compared. The operating voltage and frequency are application specific trade off parameters. However, a 20 kHz Hertz system is suitable for wide range systems.

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IN-FLIGHT CREW TRAINING

STATS

IN-FLIGHT CREW TRAINING

WHITE PAPER

DECEMBER 1989

Charles Gott
Peter Galicki FM8
NASA-JSC

David Shores
Barris Technology

It is a well known fact that computer generated training videotapes can significantly enhance perception of procedures and sequences such as on-orbit assembly of structures. It is much easier to show a videotape of how something works then it is to try to describe it verbally or with text and 2-D drawings. One can carry this observation one step further - to actually project the trainee into a life-like computer generated 3-D training scenario with a Helmet Display System.

It is easier to relate to a videatape because it communicates thru graphical means - easy and natural for everybody to understand. Still the trainee is only playing a passive role of an observer - he can't reach out and interact with objects on a videotape, just as he can't change the viewing angle. Helmet Mounted Displays make it possible for someone to actually project himself into a virtual environment and take an active role in their training. Just like the video training films are stored on cassette tapes, life-like 3-D training scenarios can be stored in cassete modules. Instead of placing a videotape in a VCR, the trainee plugs in a scenario module into the computer and puts on a Helmet Mounted Display to find himself surrounded by that scenario. Here is one possible application for such system :

A system on board of Space Station Freedom developes a fault. A decision is made to repair the fault locally with minimum loss of time. None of the crew, however, has been trained to deal with this particular emergency. The selected Astronaut has to quickly absorb the maitenance procedures, make few practice runs to build up confidence and finally perform the actual repair.

The crewperson loads the simulated mission cartridge, dons the Helmet Mounted Display and is immiediately projected into a "3-D training manual". Unlike a conventional repair manual this one has no pages, instead it surrounds the trainee with a life-like 3-dimensional representation of the

faulty system and it's surroundings. On the first pass the trainee can simply sit back and watch the faulty system repair itself. If a different viewing angle is desired, all the trainee has to do is to move his head to a new viewing position. The view changes automatically just as it would in real life. In this part of the accelerated training the astronaut is assuming a passive role of essentially watching a 3-dimensional videotape of repair procedures. Following a few minutes of passive observation the astronaut can place his hand on, for example, a module being replaced in a chassis. He can now actively follow the repair sequence by interacting with moving objects in the scenario. This active participation in the simulation scenario has the feel and sound of hands-on training. After several active passes in the virtual (computer generated) environment the crew is now ready to repeat the repair on the real system with full confidence.
The in-flight crew trainer will provide more effective training simulations thru video or animated task descriptions and interactive training environments. The latter will include computer generated, synthetic 3-D training scenarios and active computer control of hand input peripherals for tactile training during scene playback. The system will provide accelerated in-flight training capability by refreshing crew skills and practicing unplanned contingency operations in a realistic environment. The in-flight crew trainer will also enhance crew preparedness and safety.
The in-flight crew trainer is a stand alone system consisting of up to five nodes (two helmets per node). Each node uses three digital signal processors (two DSP's to compute the graphics, the third acting as a simulation host) and four graphics processors on a single printed circuit board. The simulated environment comprises a series of wireframe and solid-shaded images. All system calculation are real-time, so as soon as the wearer moves his head, the image also moves.

The "Helmet Mounted Display System" and "Part Task Trainer" are two projects currently underway that are closely related to the in-flight crew training concept. The first project is a training simulator and an engineering analysis tool. The simulator's

unique helmet mounted display actually projects the wearer into the simulated environment of three-dimensional space. Miniature monitors are mounted in front of the wearers eyes. The images are slaved to a head tracking device which allows the system to sense that the wearer has turned 180 degrees for example, and projects the images which were previously behinnd the wearer. The system can simulate (in real time) the actions of astronauts in the Space Station Freedom cupola, Shuttle or Manned Maneuvering Unit (MMU) for coordinated training of up to ten crew members. Partial Task Trainer (PTT) is a kinematic simulator for the Shuttle Remote Manipulator System (RMS). The simulator consists of a high end graphics workstation with a high resolution color screen and a number of input peripherals (including the "Handcontroller Chair") that create a functional equivalent of the RMS control panel in the back of the Orbiter. PTT is being used in the training cycle for Shuttle crew members. It provides inexpensive hands-on training in an environment where mistakes can cause no damage to hardware. PTT has been designed to augument large scale simulators that are expensive to operate. It allows the crew members more time to work with the Shuttle RMS and learn different modes of operation. Activities are curently underway to expand the capability of the Helmet Display System and the Partial Task Trainer. Lower system complexity, higher fidelity graphics and improved processing speed are among many performance improvements that could benefit the respective projects as well as the in-flight crew trainer.

Researchers involved in these projects include Peter Galicki (NASA/JSC) and David Shores (Barrios Technology). Peter Galicki is conducting research in real-time computer hardware and interfacing. He is also involved in the development of Helmet Display technology and it's applications to JSC programs. David Shores is a computer graphics software engineer specializing in simulation development and synthesis for high end, color graphics workstations.

Most of the research for the in-flight crew trainer will be conducted at JSC's Integrated Graphics and Operations Analysis Laboratory (IGOAL). IGOAL's staff and high performance graphics workstations are dedicated to development of simulation and engineering analysis tools as well as graphics synthesis algorithms. IGOAL's man-in-the-loop simulators include Shuttle Remote Manipulator System (RMS) simulator and Space Station RMS simulator. Proximity operations simulators in the IGOAL support Shuttle, Shuttle-C, OMV and MMU. IGOAL is also involved in the development of Helmet Display technology with one Helmet System operational and an upgraded system under development. In addition a custom peripheral decelopment facility within IGOAL provides a capability to interface it's computer systems to the real world. Appart from IGOAL JSC Systems Engineering Simulator will also take part in the study of an in-flight crew trainer.

This proposed training system concept is based on many new technological breakthrus some of which are more mature then others. Third generation digital signal processors and highly integrated graphics chips dramatically improve data processing performance making it possible to shrink the entire processing system to a single board. After the graphical images are computed they require a high resolution color miniature monitor for display. Color miniature displays that can be mounted on a helmet are not currently readily available and could represent a potential "hole". On the other hand, real-time head trackers are in production and their operation and interfacing are well understood. Integration of the trainer with existing flight systems should be straight forward and could provide for the interaction of multiple trainees within a common simulated environment. Low weight, volume and power requirements should be met by high component integration. Local storage of "digital" training scenarios are being investigated as well as remote transmission of training sessions from the ground.

PAYLOAD ACCOMMODATIONS PANEL

732

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46P

PRESENTATION 3.3.1

N91-17045

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SPACE SHUTTLE

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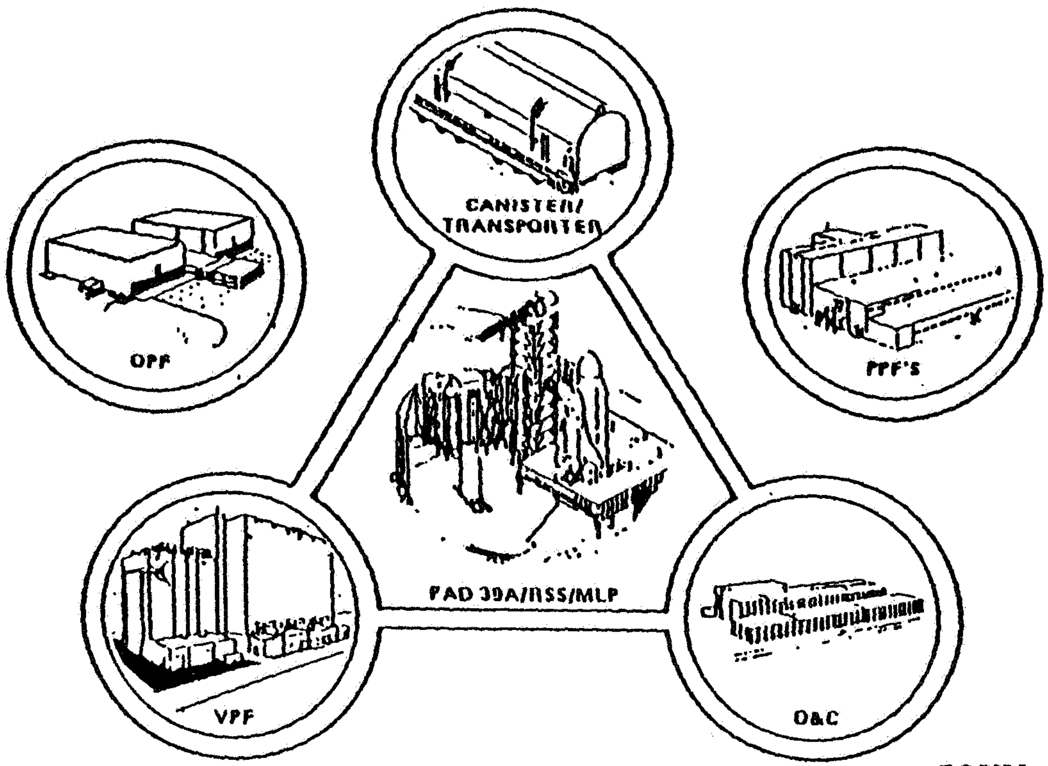

JOHN MORIAN
NASA HEADQUARTERS
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PURPOSE

THIS PRESENTATION IS INTENDED TO PROVIDE A BASIC UNDERSTANDING OF THE NSTS PAYLOAD PROCESSING OPERATIONS PERFORMED AT JOHN F. KENNEDY SPACE CENTER (KSC) AND TO DESCRIBE THE PAYLOAD FACILITIES, SUPPORT SERVICES, AND GROUND SUPPORT EQUIPMENT USED TO SUPPORT THAT PROCESS.

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CONTENTS

KSC OPERATIONS

- O KSC IS THE PRIMARY NASA LAUNCH SITE
  - \- RESPONSIBLE FOR THE MANAGEMENT AND DIRECTION OF:
    - o ASSEMBLY AND PROCESSING OF THE TDRS, MAGELLAN, GALILEO, SPACELAB, AND SIMILAR TYPE PAYLOADS
    - o SUPPORT OF PAYLOAD PROCESSING AND FINAL PREPARATION FOR LAUNCH
    - o FINAL TEST AND INTEGRATION OF PAYLOADS IN THE ORBITER BAY BEFORE LAUNCH
    - o FINAL TEST AND INTEGRATION OF PAYLOADS WITH EXPENDABLE VEHICLES
    - o DEINTEGRATION OF PAYLOADS FROM THE SPACE TRANSPORTATION SYSTEM (STS) UPON THEIR RETURN FROM SPACE

ARRIVAL/DEPARTURE

O PAYLOAD AND ASSOCIATED GROUND SUPPORT EQUIPMENT CAN BE DELIVERED TO KSC VIA:

- LAND: FLORIDA EAST COAST RAILWAY
  INTERSTATE HIGHWAY 95
- AIR: ORLANDO INTERNATIONAL AIRPORT
  MELBOURNE REGIONAL AIRPORT
  KSC'S SHUTTLE LANDING STRIP
  CAPE CANAVERAL AIR FORCE STATION (CCAFS) SKID STRIP
  SPACEPORT EXECUTIVE AIRPORT (TICO)
- SEA: INTERNATIONAL SEAPORT OF ENTRY AT PORT CANAVERAL
  INTERCOASTAL WATERWAY

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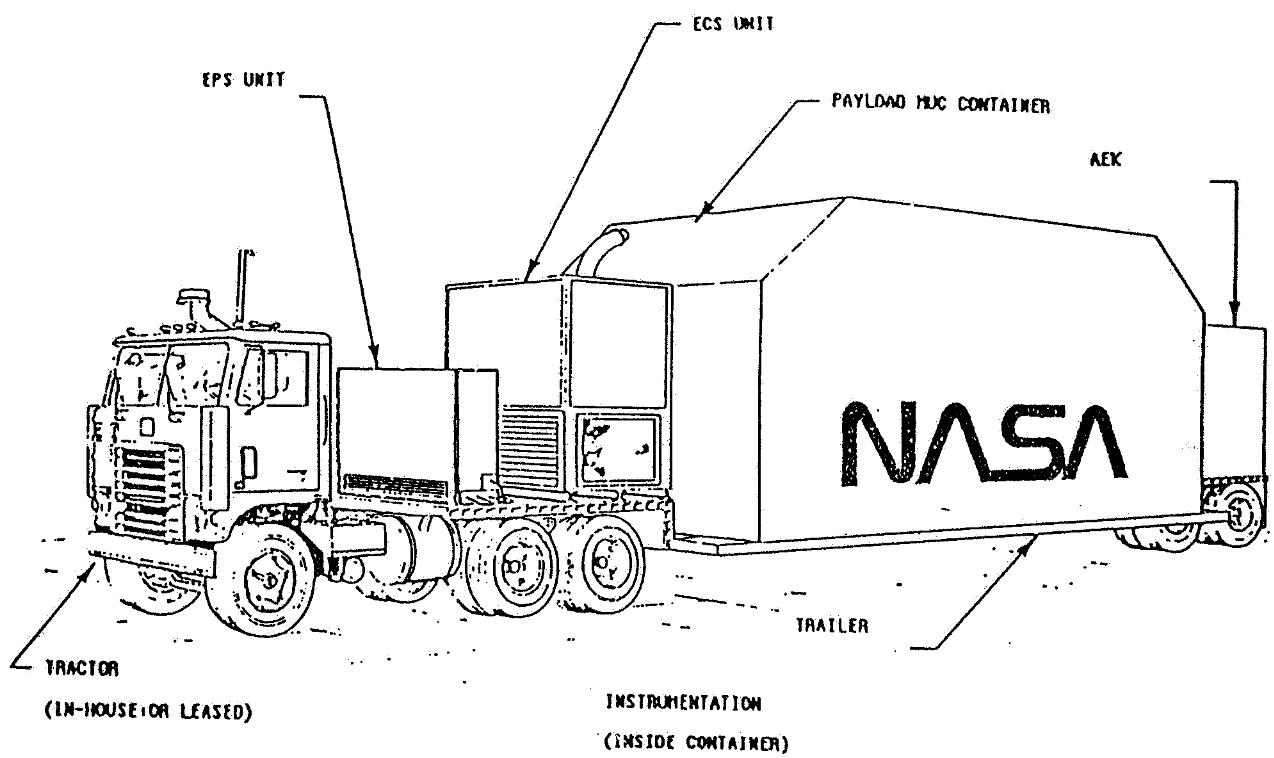

NOTE: PETS MUC HEIGHT CAN BE INCREASED BY INSTALLING TWO OPTIONAL SPACERS.

Payload Environmental Transportation System (PETS)

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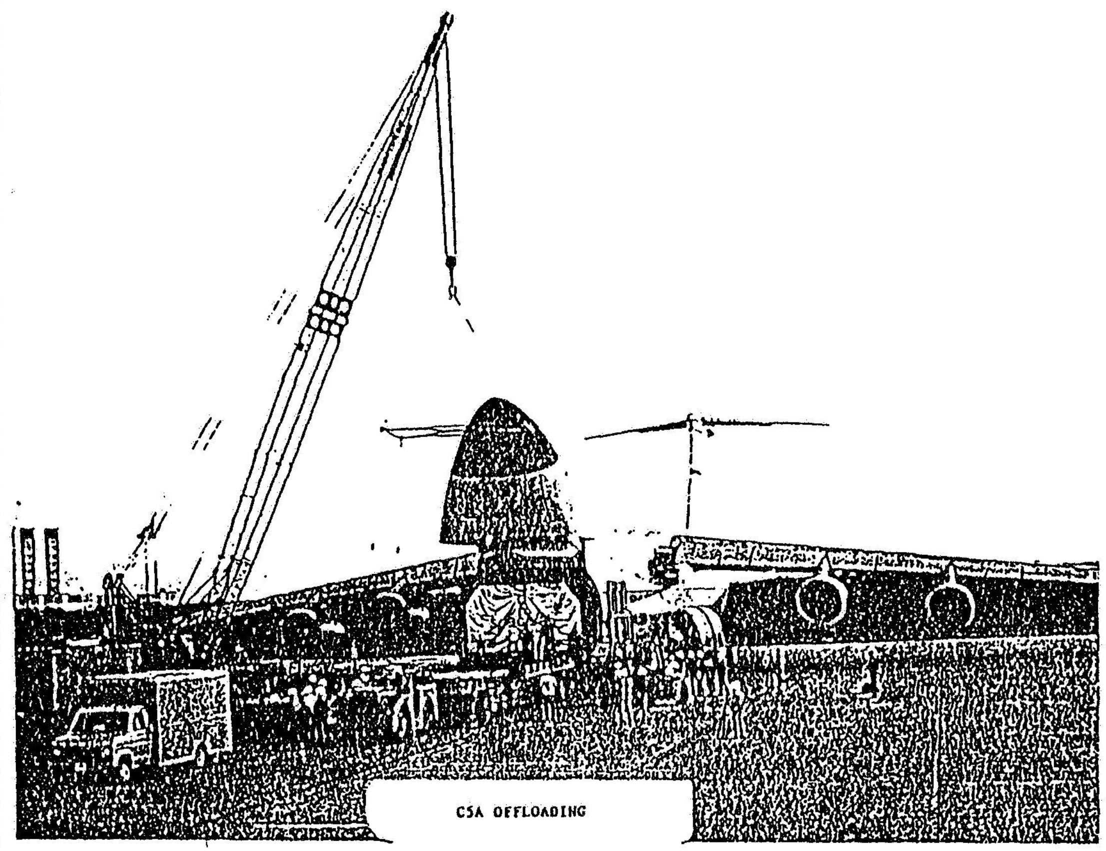

CSA OFFLOADING

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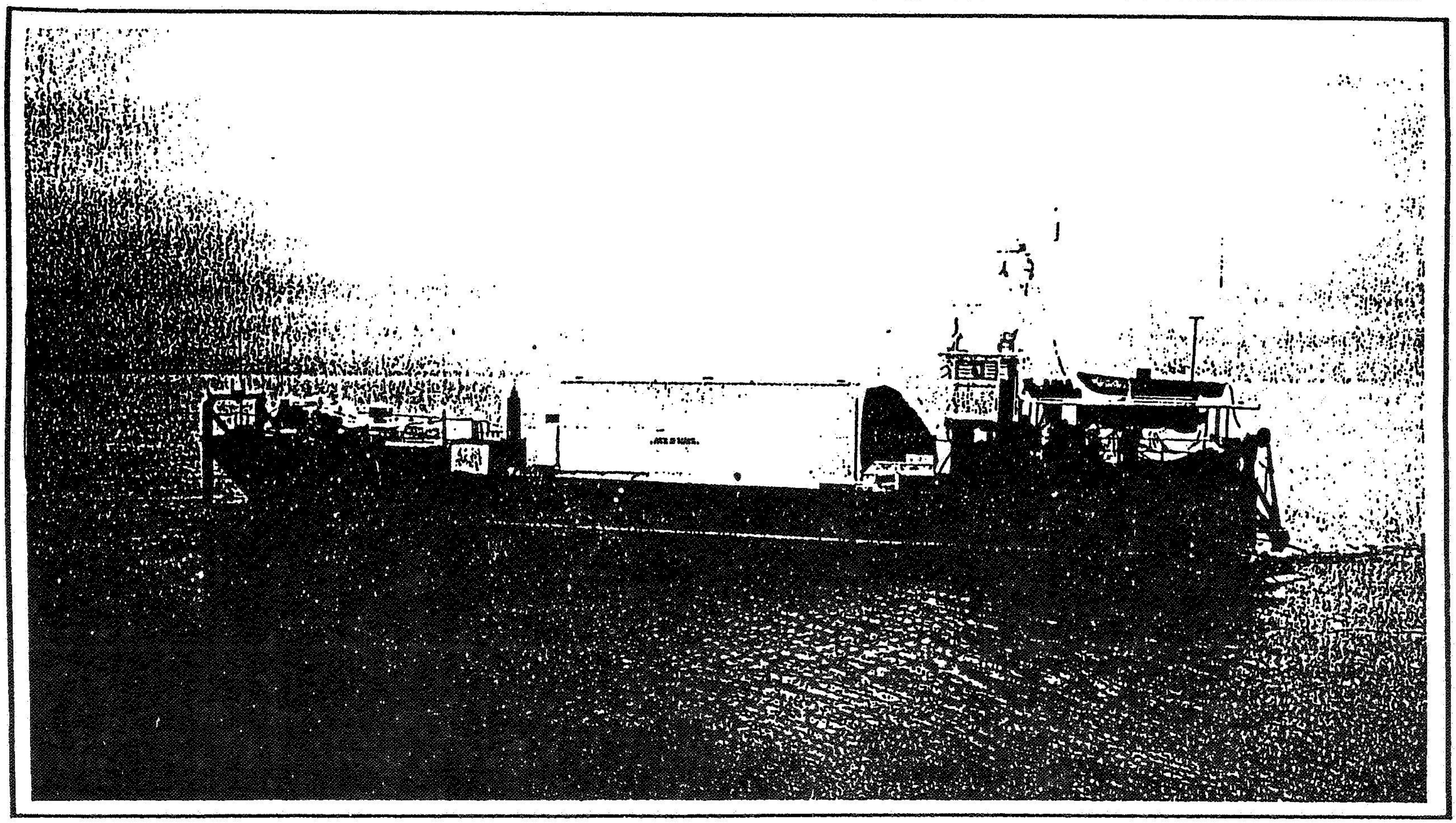

ARRIVAL BY CUSTOMER LEASED SHIP

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PAYLOAD CLASSIFICATIONS

- O HORIZONTAL - PAYLOADS WHICH ARE PLACED INTO THE ORBITER CARGO BAY WHILE THE ORBITER IS IN THE HORIZONTAL IN THE ORBITAL PROCESSING FACILITY (OPF)
- O VERTICAL - PAYLOAD WHICH ARE PLACED INTO THE ORBITER CARGO BAY WHILE THE ORBITER IS IN THE VERTICAL IN THE PAYLOAD CHANGEOUT ROOM (PCR)
- O MIXED
- O SPECIAL
  - o STUDENT INVOLVEMENT PROJECTS
  - o GET-AWAY SPECIALS (GAS)
  - o MIDDECK EQUIPMENT
  - o MIDDECK LOCKERS

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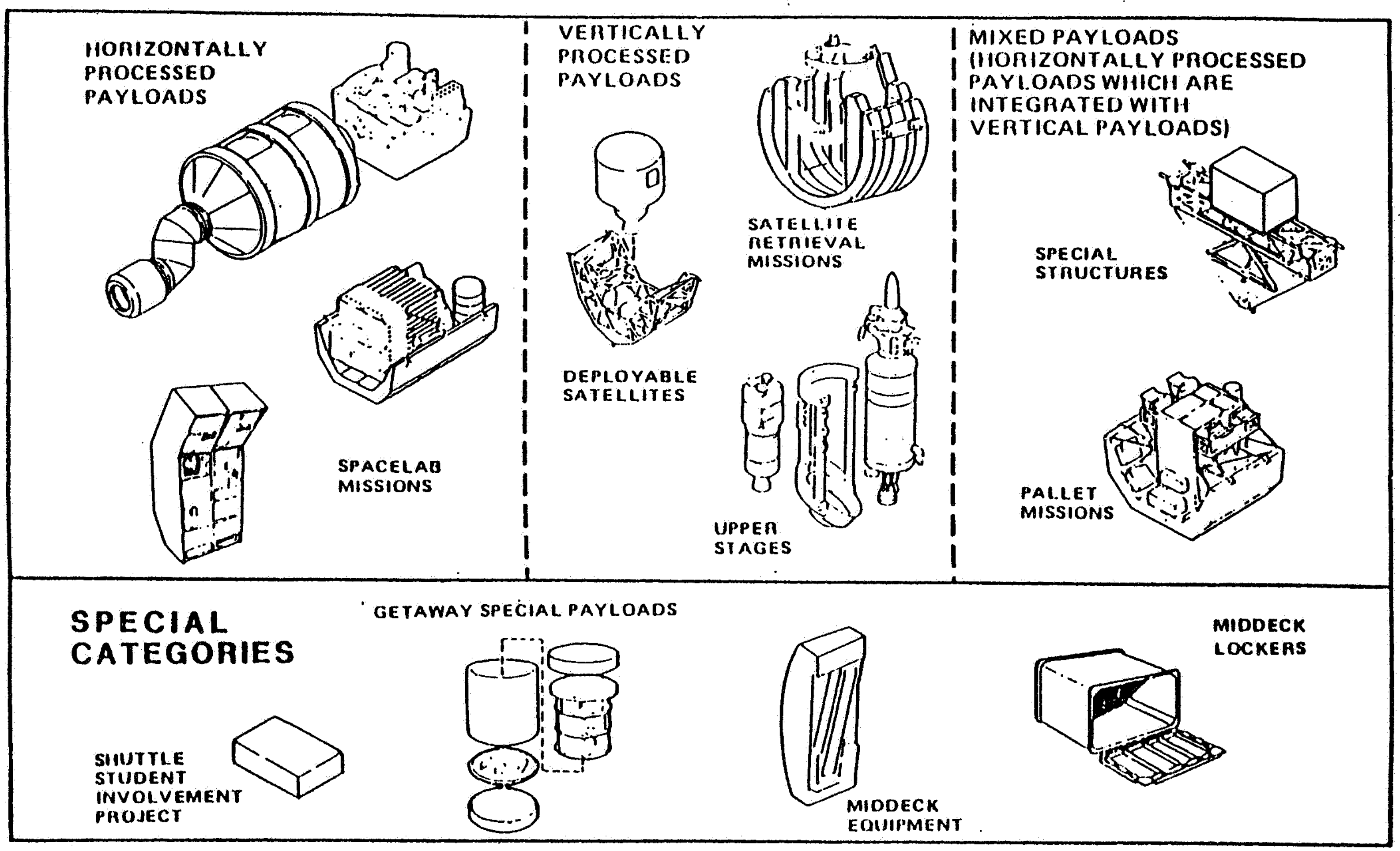

STS PAYLOADS PROCESSING CLASSIFICATIONS

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PAYLOAD PROCESSING FLOWS AT KSC

- O STS PAYLOADS
  - o HORIZONTAL
    - \- PROCESSED AND INTEGRATED IN THE O&C BUILDING
      - \- SPACE CORE AND EXPERIMENT MODULES
      - \- PALLETS, RACKS, SPECIAL STRUCTURES
  - o VERTICAL
    - \- PROCESSED THROUGH THE PAYLOAD PROCESSING FACILITY (PPF) AND THE HAZARDOUS PROCESSING FACILITY (HPF) AND/OR INTEGRATED IN THE VPF
      - \- SCIENTIFIC
      - \- PLANETARY
- O EXPENDABLE LAUNCH VEHICLE (ELV) PAYLOADS
  - \- PROCESSED THROUGH THE PPF AND HPF THEN TRANSPORTED DIRECTLY TO THE LAUNCH VEHICLE

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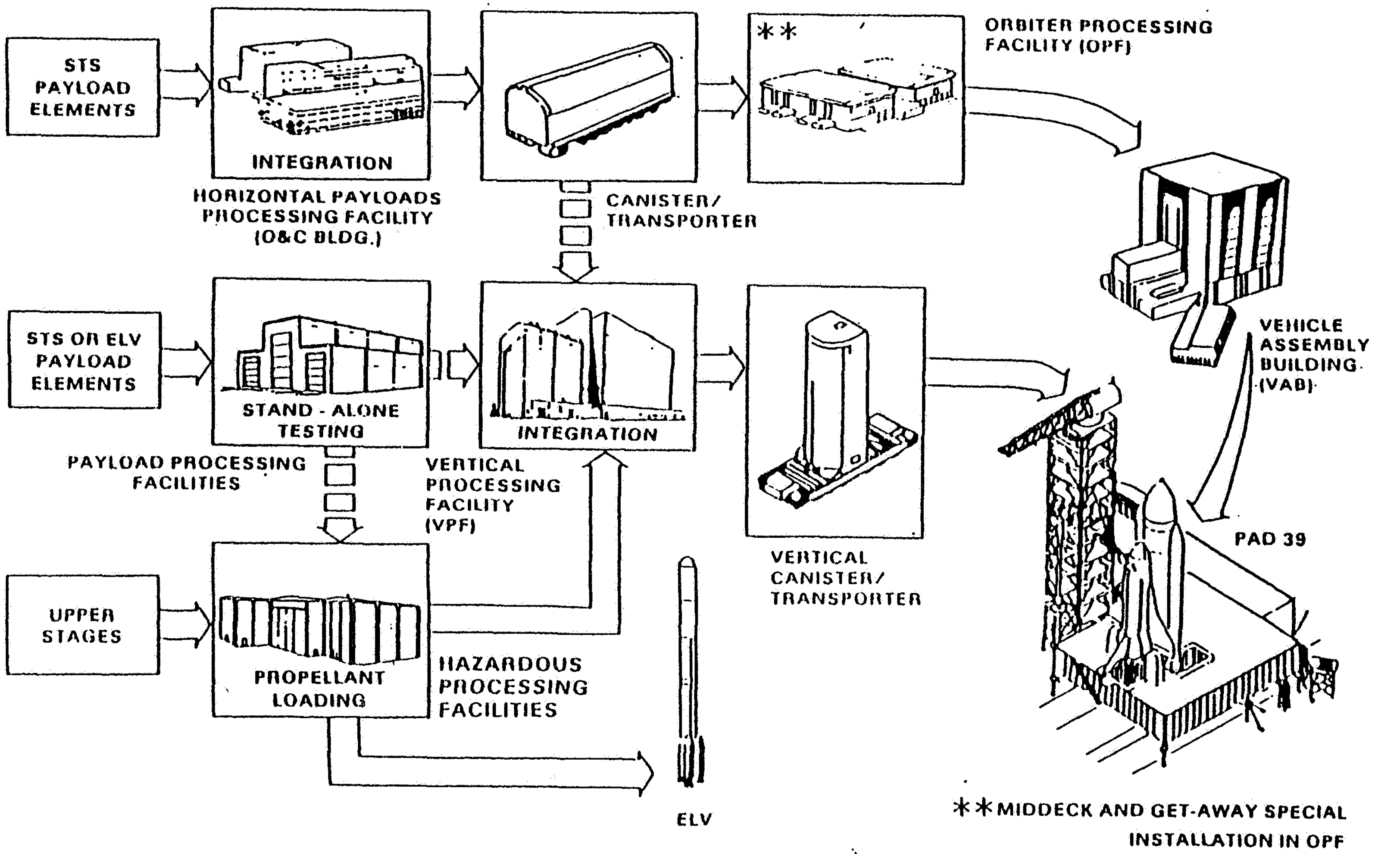

PAYLOAD PROCESSING FLOWS AT KSC

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MULTI-USE MISSION SUPPORT EQUIPMENT (MMSE)

- PAYLOAD CANISTER (2 EACH)
- PAYLOAD CANISTER TRANSPORTER (2 EACH)
- PAYLOAD STRONGBACK
- PAYLOAD HANDLING FIXTURE

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CANISTER/TRANSPORTER

- AN ENVIRONMENTALLY CONTROLLED, TRANSPORTATION CONTAINER USED TO TRANSPORT ALL SHUTTLE PAYLOADS BETWEEN FACILITIES
- WEIGHS APPROXIMATELY 107,000 POUNDS
- MOUNTED ON THE TRANSPORTER IN THE VERTICAL OR HORIZONTAL POSITION
- PROVIDES ESSENTIALLY THE SAME MECHANICAL SUPPORT TO PAYLOAD ELEMENTS AS THE ORBITER
- PAYLOAD RESTRAINED IN THE "Y" DIRECTION BY MEANS OF A SINGLE OR DOUBLE "Y" RESTRAINT SYSTEM (KSC DRAWING 79K20001) WHICH RESTRAINS LONGERON TRUNNION (KEEL TRUNNION FREE)
- DESIGN TO SUPPORT A 65,000 POUND PAYLOAD ASSEMBLY
- SPECIFICATION DOCUMENT FOR CANISTER IS "PAYLOAD CANISTER STANDARD INTERFACE DOCUMENT," 79K12170

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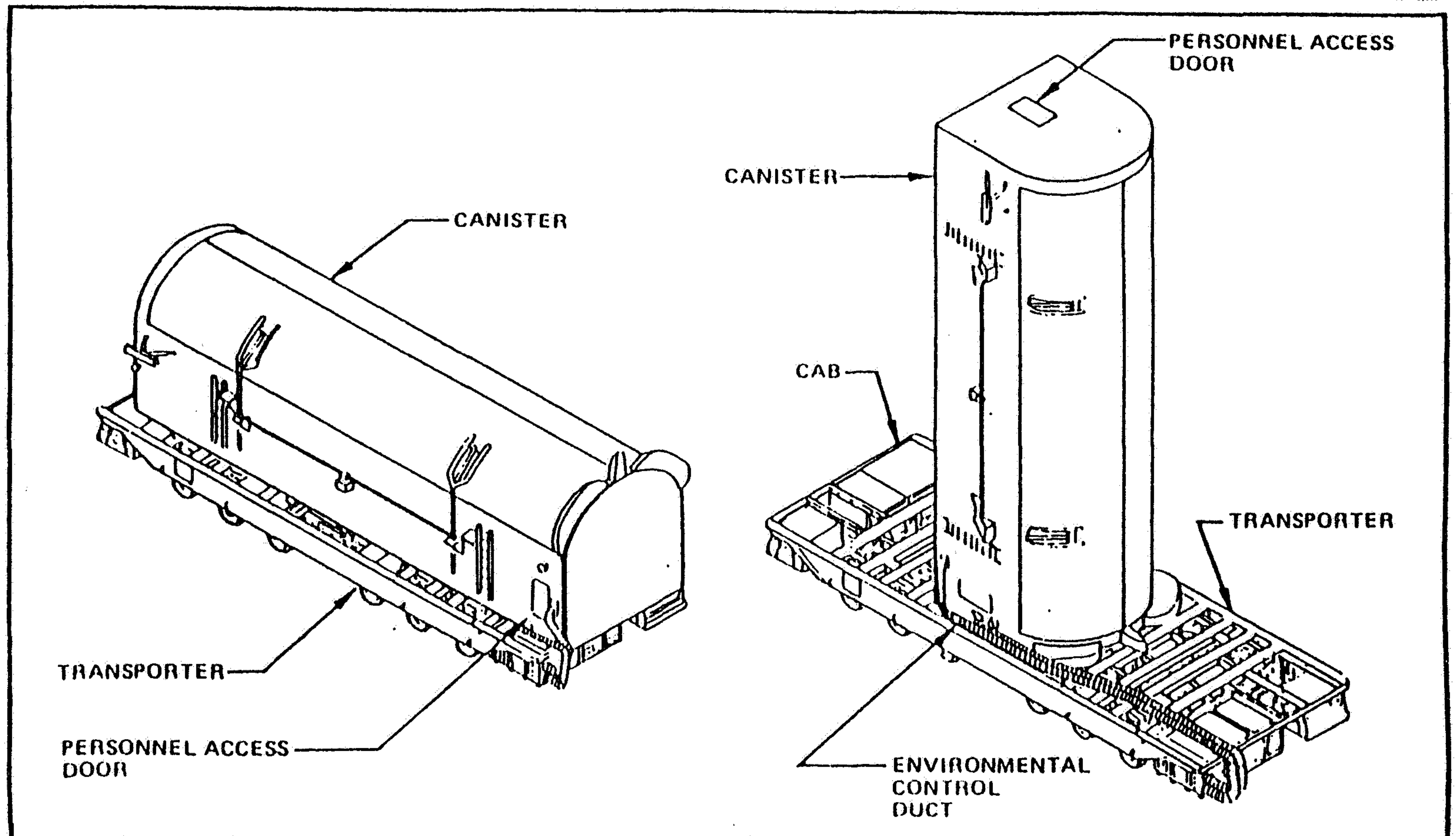

CANISTER/TRANSPORTER CONFIGURATIONS

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PAYLOAD STRONG BACK

- SUPPORTS HORIZONTALLY PROCESSED PAYLOAD SECTIONS AND POST FLIGHT PAYLOAD AND AIRBORNE SUPPORT EQUIPMENT (ASE) REMOVAL

PAYLOAD HANDLING FIXTURE

- DESIGNED TO HANDLE SHUTTLE PAYLOADS AT THE CONTINGENCY LANDING SITES. CAN BE AIRLIFTED BY C-5A AIRCRAFT

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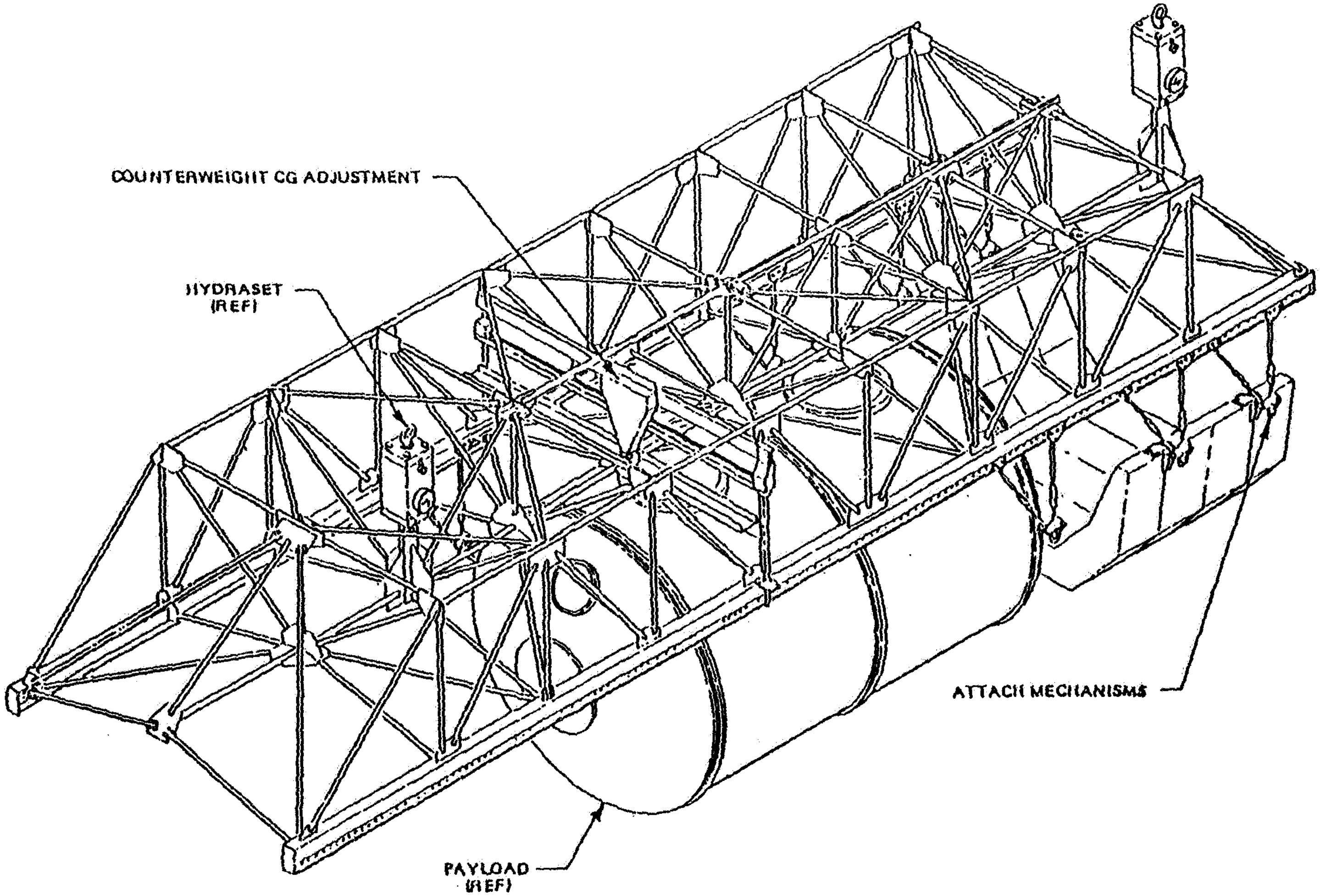

PAYLOAD STRONGBACK

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PAYLOAD PROCESSING FACILITIES

KSC FACILITIES

- 0 RADIOISOTOPE THERMOELECTRIC GENERATOR (RTG) STORAGE BUILDING
- 0 VERTICAL PROCESSING FACILITY (VPF)
- 0 PAYLOAD HAZARDOUS SERVICING FACILITY (PHSF)
- 0 SPACECRAFT ASSEMBLY AND ENCAPSULATION FACILITY (SAEF-2)
- 0 OPERATIONS AND CHECKOUT (O&C) BUILDING
- 0 ORBITER PROCESSING FACILITY (OPF)
- 0 ROTATING SERVICE STRUCTURE/PAYLOAD CHANGEOUT ROOM (RSS/PCR)

CCAFS FACILITIES

- 0 PAYLOAD SPIN TEST FACILITY (PSTF)
- 0 HANGAR S - A PPF
- 0 AE BUILDING - A PPF
- 0 AM BUILDING - A PPF
- 0 AO BUILDING - A PPF
- 0 LIFE SCIENCES SUPPORT FACILITY (LSSF)/HANGAR L
- 0 EXPLOSIVE SAFE AREA (ESA 60)

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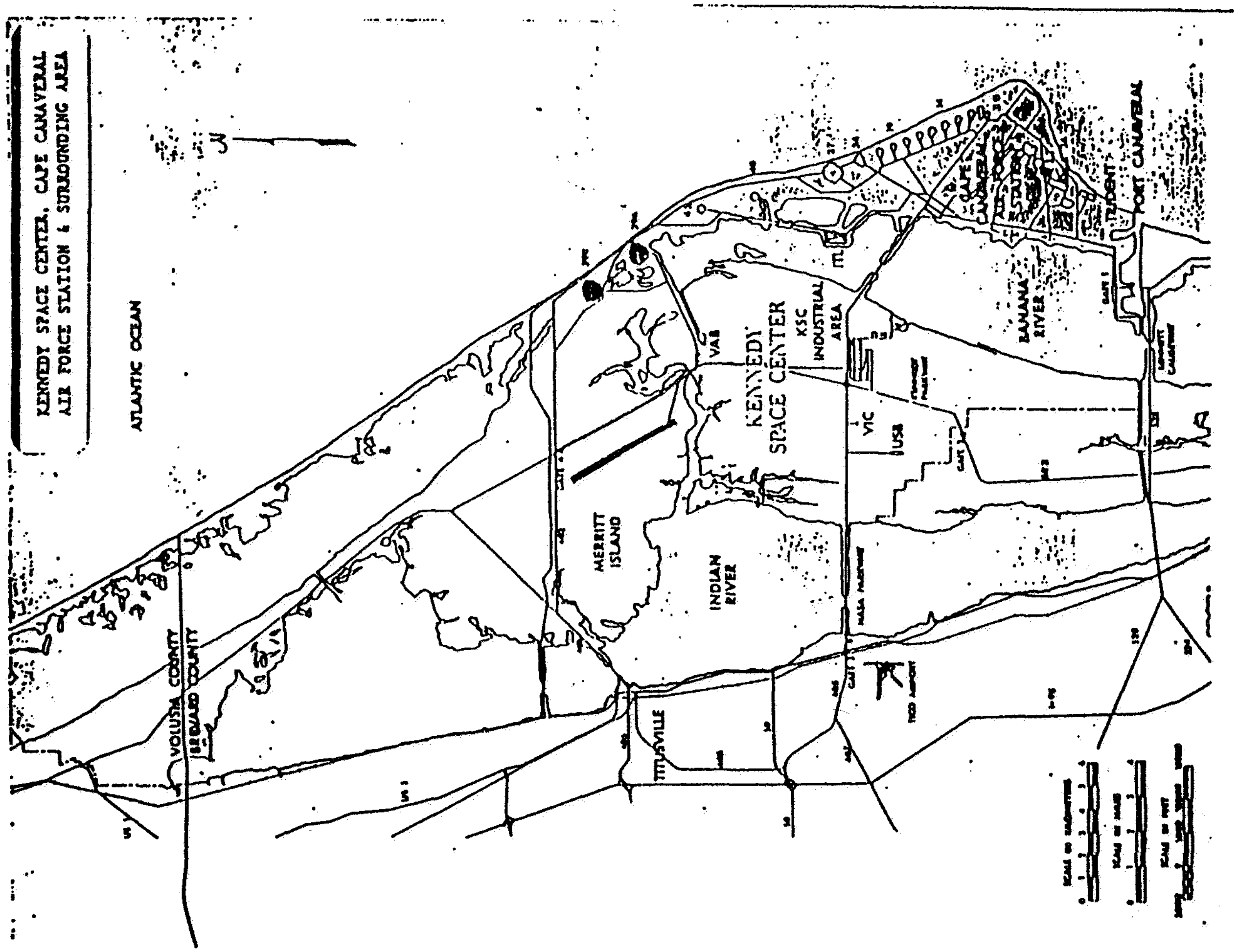

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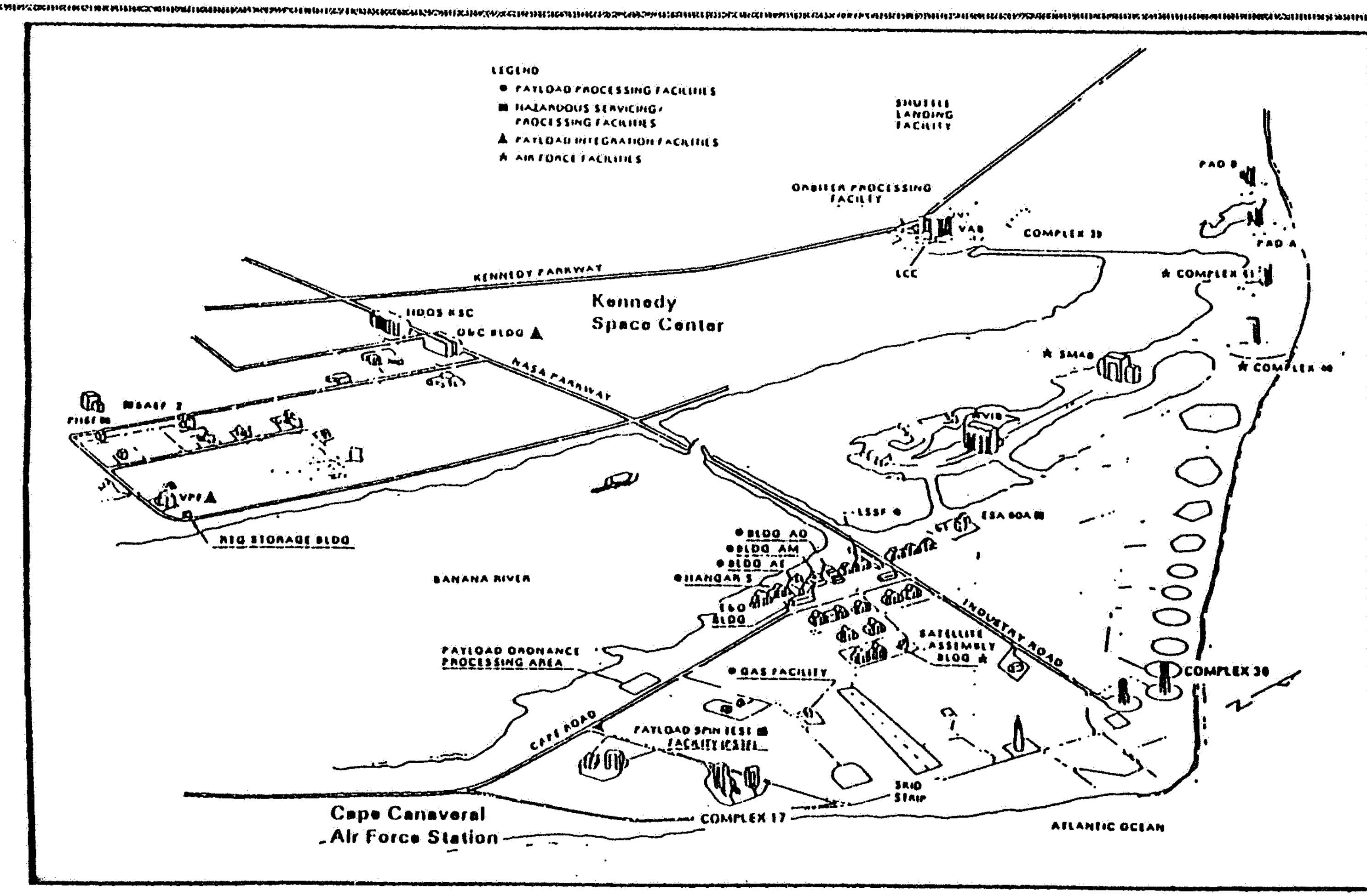

PAYLOAD FACILITIES

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EXAMPLES OF HORIZONTAL PAYLOAD FLOWS

- SPACELAB MODULES
- IGLOOS
- PALLETS
- MISSION PECULIAR EXPERIMENT SUPPORT STRUCTURES THAT CARRY SCIENTIFIC EXPERIMENTS ARE PROCESSED AND INTEGRATED IN THE O&C BUILDING

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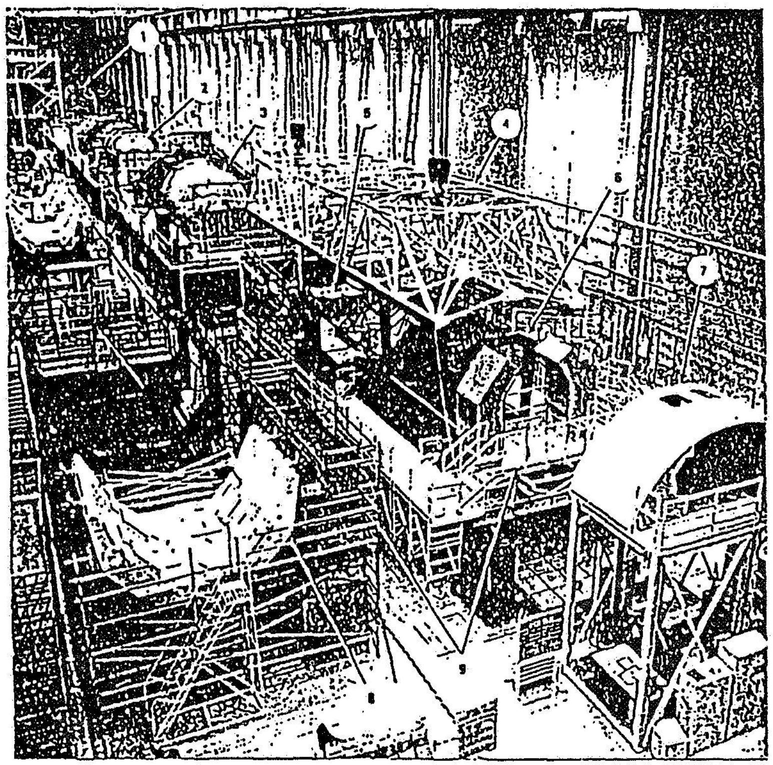
HORIZONTAL (PAYLOAD) PROCESSING FACILITY AND GSE

OPERATIONS AND CHECKOUT BUILDING
(LOOKING EAST – MAY 16, 1983)



1. PAYLOAD CANISTER
2. SPACELAB MODULE (ENGINEERING MODEL)
3. SPACELAB 1 IN INTEGRATION STAND
4. MMSE STRONGBACK LIFTING OSTA-2
5. OSTA-2 PAYLOAD IN LEVEL IV SHORT TRUNNION SUPPORT FIXTURE
6. SPACELAB RACKS EXTERNAL BRACES KIT
7. LEVEL IV AFT FLIGHT DECK SIMULATOR
8. SPACELAB 2 PALLET IN NORTH LEVEL IV WORKSTAND
9. LEVEL IV ACCESS EQUIPMENT

LEGEND:

YELLOW – ACCESS EQUIPMENT
BLUE – SELECTED SPACELAB GSE

HORIZONTAL PAYLOAD FACILITIES
KSC O&C BUILDING
ASSEMBLY AND TEST AREA

O EXPERIMENT INTEGRATION STANDS

- PROVIDE FOR PALLET AND RACK TRAIN ASSEMBLY AND EXPERIMENT INTEGRATION

O SPACELAB INTEGRATION STANDS

- PROVIDE FOR SPACELAB MODULE PREPARATION AND EXPERIMENT RACK TRAIN INTO THE MODULE, PALLET-TO-MODULE MATING, AS WELL AS SYSTEMS CHECKOUT AND VERIFICATION

O CITE STAND

- PROVIDES FOR HORIZONTAL PAYLOAD TESTING AND CHECKOUT IN AN ELECTRONIC ENVIRONMENT USING ORBITER AVIONICS

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PAYLOAD-TO-ORBITER INTERFACE VERIFICATION

- INTERFACE VERIFIED OFF-LINE WITH PAYLOAD INTERFACE TEST EQUIPMENT (CITE):
  - LOCATED IN THE O&C BUILDING (HORIZONTAL PAYLOAD) AND IN THE VPF (VERTICAL PLAYLOAD)
  - CONTAINS OVER 100 RACKS OF ELECTRONIC/COMPUTER EQUIPMENT TO PROVIDE HIGH FIDELITY SIMULATION OF THE PAYLOAD-TO-ORBITER INTERFACE
  - VERIFIES ORBITER AFT FLIGHT DECK CONTROL OF PAYLOADS
  - PROVIDES ORBITER POWER FOR PAYLOADS
  - ENABLES FAULT DETECTION/CAUTION AND WARNING
  - VERIFIES PAYLOAD ENGINEERING AND SCIENCE DATA AND COMMAND/CONTROL
- INTERFACE VERIFIED ON-LINE WITH PAYLOAD IN THE ORBITER
  - REQUIREMENTS IDENTIFIED IN PAYLOAD INTEGRATION PLAN (PIP) ANNEX 9
  - PAYLOAD INTERFACE VERIFICATION PER OPERATIONAL MAINTENANCE REQUIREMENTS SPECIFICATION DOCUMENT (OMRSD) FILE II

ORBITER OPERATIONS

O ORBITER PROCESSING FACILITY

- PRELAUNCH
  - o INSTALL PAYLOADS AS APPLICABLE
  - o WEIGH AND DETERMINE CENTER OF GRAVITY
  - o DISCONTINUE PAYLOAD BAY ENVIRONMENTAL CONTROL DURING ROLL OVER TO VERTICAL ASSEMBLY BUILDING
- POSTLANDING
  - o REMOVAL OF PAYLOADS AND/OR PAYLOAD AEROSPACE SUPPORT EQUIPMENT

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EXAMPLES OF VERTICAL PAYLOAD FLOWS

SPACECRAFT SUCH AS THE TDRS, MAGELLAN, GALILEO, SYN COM-IV, AND INMARSAT II ARE PROCESSED AND INTEGRATED IN THE VPF.

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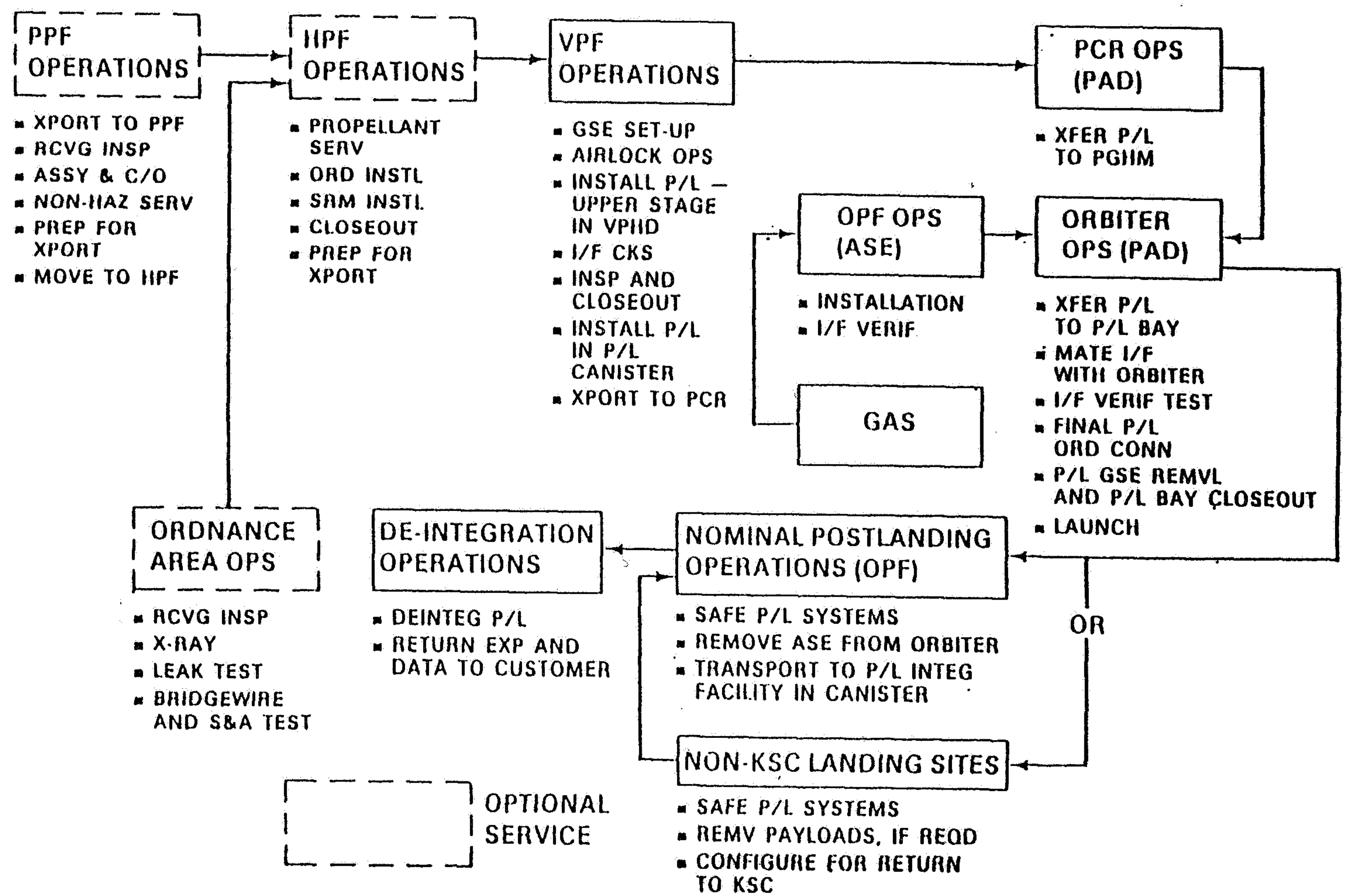
EXAMPLE OF VERTICAL PAYLOAD FLOW FOR VPF INTEGRATION



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PAYLOAD PROCESSING FACILITY (PPF) ACTIVITIES

- O PAYLOAD PROCESSING BEGINS UPON ARRIVAL OF THE PAYLOAD AND GROUND SUPPORT EQUIPMENT AT ONE OF THE EXISTING PPFs
- O SET UP ELECTRICAL GROUND SUPPORT EQUIPMENT STATION
  - TO MONITOR AND CONDUCT PAYLOAD CHECKOUT VIA HARDLINES AND OPEN LOOP RADIATION DURING THE ASSEMBLY AND VERIFICATION PROCESS
- O FINAL ASSEMBLY/BUILDUP OF PAYLOAD TO LAUNCH CONFIGURATION
  - INITIAL PRESSURE AND PROPELLANT SYSTEMS LEAK TESTS
  - ASSEMBLY OF PAYLOAD SECTIONS
  - INSTALLATION OF SOLAR PANELS, ANTENNAS, INSULATION, ETC.
  - PAYLOAD FUNCTIONAL TESTING WITH PAYLOAD-UNIQUE GROUND SUPPORT EQUIPMENT

PAYLOAD HAZARDOUS SERVICING FACILITY

- USED FOR HAZARDOUS FUEL LOADING AND ORDNANCE SERVICING
- CAN ACCOMMODATE THE LARGEST VERTICAL OR HORIZONTALLY LOADED SPACECRAFT, INCLUDING THE PAYLOAD CANISTER

HAZARDOUS PROCESSING FACILITY (HPF) ACTIVITIES

- PAYLOAD PROCESSING CONTINUES WITH THE TRANSFER OF THE PAYLOAD TO A HPF FOR THE INSTALLATION AND SERVICING OF POTENTIALLY HAZARDOUS SYSTEMS (WHERE APPLICABLE).

- TYPICAL HAZARDOUS OPERATIONS INCLUDE:
  - SERVICING OF LIQUID PROPELLANT SYSTEMS:
    - HYDRAZINE (N_2H_4) AND UNSYMMETRICAL DIMETHOL HYDRAZINE ($N_2H_2 \cdot (CH_3)_2$)
    - NITROGEN TETROXIDE (N_2O_4) AND MONOMETHYL HYDRAZINE ($N_2H_3 \cdot CH_3$)
  - INSTALLATION OF:
    - SOLID PROPELLANT APOGEE MOTORS
    - ORDNANCE SEPARATION DEVICES
    - OTHER POTENTIALLY EXPLOSIVE OR HAZARDOUS ITEMS

- FINAL CLOSEOUT AND TESTS WITH REMOTE GROUND SUPPORT EQUIPMENT

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UPPER STAGE PROCESSING OPERATIONS

0 SOLID UPPER STAGE (SUS) PROCESSING INVOLVES PREPARATION OF THE SOLID MOTOR, THE TURNAROUND OF THE CRADLE/AIRBORNE SUPPORT EQUIPMENT (ASE), AND PAYLOAD MATING

0 SOLID MOTOR PREPARATIONS:
- STORAGE
- COLD SOAK
- X-RAY
- BUILDUP TO FLIGHT CONFIGURATION

0 DYNAMIC SPIN BALANCE OPERATIONS

0 TURNAROUND OF THE CRADLE/ASE/PAYLOAD MATE
- TEST AND RECERTIFY CRADLE/ASE
- MATE SOLID MOTOR TO CRADLE/ASE
- TEST FINAL STAGE /CRADLE ASSEMBLY
- MATE STAGE WITH PAYLOAD
- INSTALL SUNSHIELD
- PERFORM PAYLOAD INTERFACE VERIFICATION

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HANGARS AE, AO, AM

- USED TO PROCESS LARGE NON HAZARDOUS AUTOMATED SPACECRAFT

HANGAR S

- USED TO PREPARE FREE FLYER PALLETS

HANGAR L

- USED TO HOUSE LIVE SPECIMENS FOR LIFE SCIENCES PAYLOADS

PAYLOAD SPIN TEST FACILITY (PSTF)

- PRIMARILY USED TO PROCESS DELTA AND AGENA STAGES

EXPLOSIVE SAFE AREA (ESA 60)

- USED TO INTEGRATE UPPER STAGES FOR GEOSYNCHRONOUS SATELLITES, SUCH AS THE PAYLOAD ASSIST MODULE (PAM)
- ALSO USED TO PROCESS ATLAS/CENTAUR ELV'S

- O RADIOISOTOPE THERMOELECTRIC GENERATOR (RTG) STORAGE BUILDING
  - o USED FOR STORAGE OF RTG's USED FOR SPACECRAFT POWER GENERATING SYSTEMS

SPACECRAFT ASSEMBLY AND ENCAPSULATION FACILITY (SAEF-2)

- O USED TO ASSEMBLE, TEST, ENCAPSULATE AND STERILIZE HEAVY MID-SIZED PAYLOADS

VERTICAL PROCESSING FACILITY (VPF) ACTIVITIES

- PAYLOAD INTEGRATION WITH ORBITER SYSTEMS AND OTHER PAYLOADS ALSO TAKES PLACE IN THE VPF

- DELIVERY CONFIGURATION VARIES DEPENDING ON THE UPPER STAGE:
  - PAM ALREADY MATED WITH PAYLOAD
  - IUS/TDRS AND PAYLOAD ARRIVE SEPARATELY
  - SYNCOM CLASS AND ITS PERIGEE KICK MOTOR (PKM) ARRIVE SEPARATELY

- PAYLOAD ELEMENTS STACKING AND TESTS INVOLVE:
  - MATING WITH UPPER STAGE AS NECESSARY AND INSTALLATION INTO WORKSTAND IN PAYLOAD BAY SEQUENCE
  - STANDALONE HEALTH AND STATUS TESTS
  - INTEGRATION TESTS
    - ORBITER-TO-PAYLOAD INTERFACE VERIFICATION WITH PAYLOAD INTEGRATION TEST EQUIPMENT (CITE)
    - MISSION SEQUENCE TEST

PAYLOAD CHANGEOUT ROOM (PCR)

- THE PCR ATTACHED TO THE ROTATING SERVICE STRUCTURE (RSS) AT THE LAUNCH PAD IS AN ENVIRONMENTALLY CONTROLLED FACILITY WHERE THE SHUTTLE PAYLOAD IS DELIVERED AND VERTICALLY INSTALLED IN THE PAYLOAD BAY.

SPACE SHUTTLE

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PAYLOAD CHANGEOUT ROOM (PCR) OPERATIONS

- ENVIRONMENTAL MONITORING AND CONTAMINATION CONTROL PER K-STSM-14.2.1, KSC PAYLOAD FACILITY CONTAMINATION CONTROL REQUIREMENTS/PLAN
- PAYLOAD INSTALLATION IN PAYLOAD GROND HANDLING MECHANISM (PGHM)
- PAYLOAD STAND ALONE-ACTIVITIES
- ORDNANCE OPERATIONS
- PREPARATIONS FOR ORBITER INSTALLATION
- PAYLOAD INSTALLATION INTO ORBITER
  - ACCESS IS CONTROLLED
  - TRAINING IS REQUIRED
  - TOOL TETHER OPERATIONS MANDATORY

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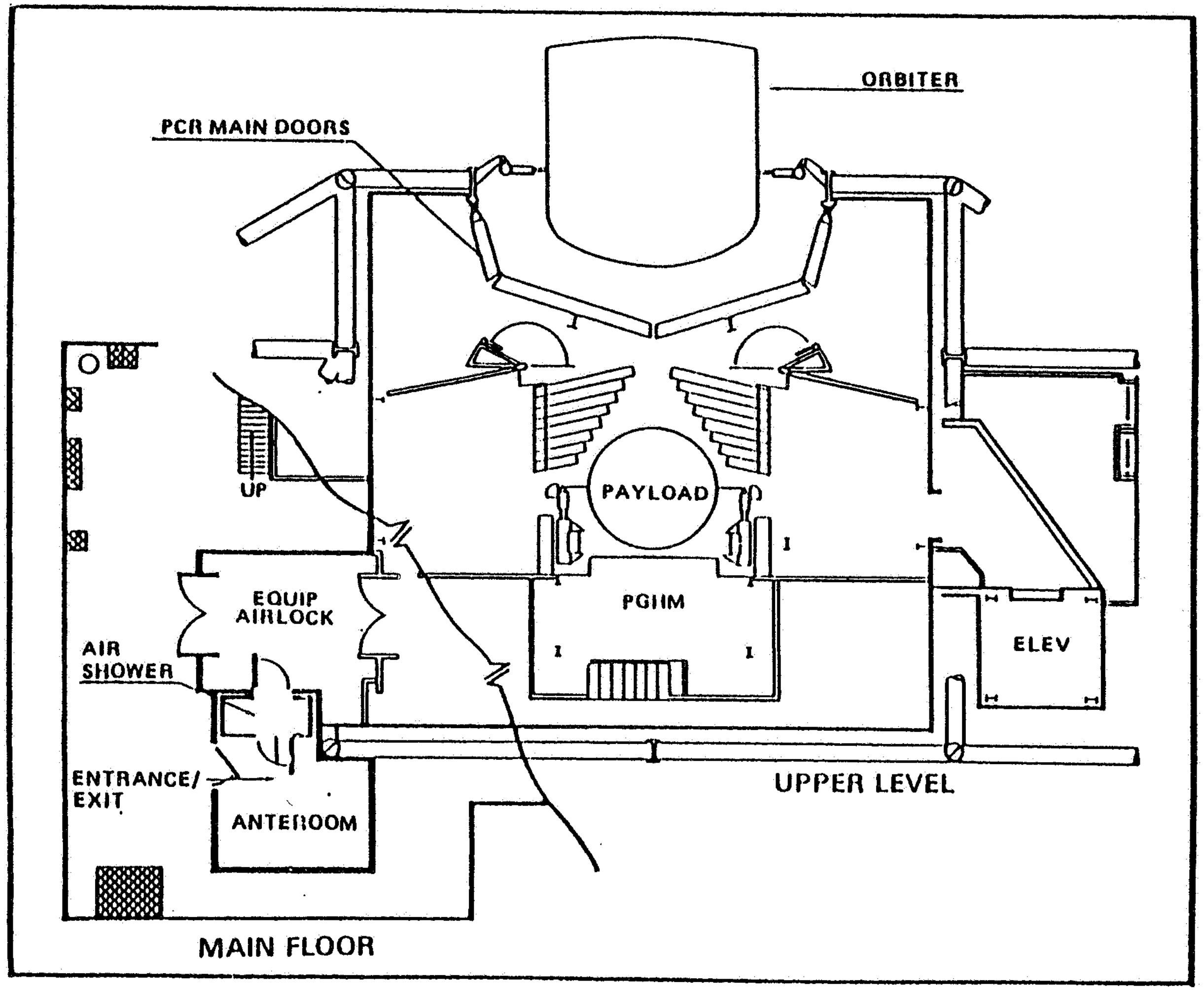

PLAN VIEW OF THE PCR

POSTLANDING OPERATIONS

- O AFTER KSC OR DRYDEN FLIGHT RESEARCH FACILITY (DFRF) LANDING AND CREW EGRESS:
  - PAYLOAD BAY ENVIRONMENTAL LIMITS ARE MAINTAINED BY EXTERIOR UNITS
  - ORBITER IS TOWED TO A PROCESSING FACILITY FOR SAFING
  - REMOVAL OF RETURNING PAYLOADS AND AIRBORNE SUPPORT EQUIPMENT - APPROXIMATELY 3 DAYS AFTER LANDING AT KSC (EITHER DIRECT LANDING OR SHUTTLE CARRIER AIRCRAFT LANDING AT KSC)
  - PAYLOADS CAN BE TURNED OVER TO PAYLOAD OWNERS AS FOLLOWS:
    - o SOME MIDDECKS CAN BE REMOVED PRIOR TO ORBITER TOW (LANDING + 2 HOURS)
    - o REMAINING MIDDECK LOCKERS CAN BE REMOVED WITHIN 24 HOURS
    - o OTHER PAYLOADS/ASE ARE REMOVED AFTER THE PAYLOAD BAY DOORS ARE OPENED (LAND AT KSC + 3 DAYS)
- O NON-KSC/DFRF LANDINGS ARE COVERED BY KVT-PL-0014 AND APPROPRIATE ANNEX, KSC OFF-SITE OPERATIONS PLAN AND KSC-PL-0012,.02, PAYLOAD OPERATIONAL LOGISITCS PLAN

SPACE SHUTTLE

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THIS CONCLUDES A BRIEF PRESENTATION OF KSC'S BROAD ROLE IN STS PAYLOAD PROCESSING, INTEGRATION, AND LAUNCH. MORE DETAILED MATERIAL IS AVAILABLE FROM JOHN MORIAN, OPERATIONS UTILIZATION DIRECTORATE.

SPACE SHUTTLE

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APPENDICES

SPACE SHUTTLE

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FACILITY HANDBOOKS

K-STSM-14.1.1	FACILITIES HANDBOOK FOR BUILDING AE
K-STSM-14.1.2	FACILITIES HANDBOOK FOR BUILDING AO
K-STSM-14.1.3	FACILITIES HANDBOOK FOR BUILDING AM
K-STSM-14.1.4	FACILITIES HANDBOOK FOR HANGAR S
K-STSM-14.1.5	FACILITIES HANDBOOK FOR PSTF
K-STSM-14.1.6	FACILITIES HANDBOOK FOR ESA-60A
K-STSM-14.1.7	FACILITIES HANDBOOK FOR SAEF-2
K-STSM-14.1.8	FACILITIES HANDBOOK FOR RTG STORAGE BUILDING
K-STSM-14.1.9	FACILITIES HANDBOOK FOR LSSF
K-STSM-14.1.10	PAYLOAD ACCOMMODATIONS AT THE RSS
K-STSM-14.1.11	FACILITIES HANDBOOK FOR PAYLOAD ORDNANCE PROCESSING AREA AT CCAFS
K-STSM-14.1.12	FACILITIES HANDBOOK FOR VPF
K-STSM-14.1.13	OPF PAYLOAD PROCESSING AND SUPPORT CAPABILITIES
K-STSM-14.1.14	O&C BUILDING PAYLOAD PROCESSING AND SUPPORT CAPABILITIES
K-STSM-14.1.15	FACILITIES HANDBOOK FOR PHSF

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ACRONYMS LIST

AEK	-	ACCESSORY EQUIPMENT KIT
ASE	-	AIRBORNE SUPPORT EQUIPMENT
CCAFS	-	CAPE CANAVERAL AIR FORCE STATION
CITE	-	CARGO INTEGRATION TEST EQUIPMENT
C/O	-	CHECKOUT
DFRF	-	DRYDEN FLIGHT RESEARCH FACILITY
DOD	-	DEPARTMENT OF DEFENSE
ECS	-	ENVIRONMENTAL CONTROL SUBSYSTEM
EGSE	-	ELECTRICAL GROUND SUPPORT EQUIPMENT
ELV	-	EXPENDABLE LAUNCH VEHICLE
EPS	-	ELECTRICAL POWER SUBSYSTEM
ESA-60	-	EXPLOSIVE SAFE AREA-60
GAS	-	GET-AWAY SPECIAL
GSE	-	GROUND SUPPORT EQUIPMENT
HPF	-	HAZARDOUS PROCESSING FACILITY
I/F	-	INTERFACE
IUS	-	INERTIAL UPPER STAGE
KSC	-	KENNEDY SPACE CENTER
LCC	-	LAUNCH CONTROL CENTER
LSSF	-	LIFE SCIENCES SUPPORT FACILITY
MMSE	-	MULTI-USE MISSION SUPPORT EQUIPMENT
MUC	-	MULTI-USE CONTAINER
OMRSD	-	OPERATIONAL MAINTENANCE REQUIREMENTS SPECIFICATION DOCUMENTS
O&C	-	OPERATIONS AND CHECKOUT BUILDING
OPF	-	ORBITER PROCESSING FACILITY
OSTA	-	OFFICE OF SPACE AND TERRESTRIAL APPLICATIONS

ACRONYMS LIST (CONTINUED)

PAM - PAYLOAD ASSIST MODULE
PCR - PAYLOAD CHANGEOUT ROOM
PETS - PAYLOAD ENVIRONMENTAL SYSTEMS (PETS)
PGHM - PAYLOAD GROUND HANDLING MECHANISM
PHSF - PAYLOAD HAZARDOUS SERVING FACILITY
PKM - PERIGEE KICK MOTOR
P/L - PAYLOAD
PPF - PAYLOAD PROCESSING FACILITY
PSTF - PAYLOAD SPIN TEST FACILITY
RSS - ROTATING SERVICE STRUCTURE
RTG - RADIOISOTOPE THERMOELECTRIC GENERATOR
SAEF - SPACECRAFT ASSEMBLY AND ENCAPSULATION FACILITY
SMAB - SOLID MOTOR ASSEMBLY BUILDING
SPIF - SHUTTLE PAYLOAD INTERFACE FACILITY
SRM - SOLID ROCKET MOTOR
SR&QA - SAFETY RELIABILITY & QUALITY ASSURANCE
STS - SPACE TRANSPORTATION SYSTEM
SUS - SOLID UPPER STAGE
TDRS - TRACKING AND DATA RELAY SATELLITE
VAB - VEHICLE ASSEMBLY BUILDING
VIB - VERTICAL INTEGRATION BUILDING
VPF - VERTICAL PROCESSING FACILITY

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PRESENTATION 3.3.2

N91-17046

AVIONICS PAYLOAD SUPPORT ARCHITECTURE

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
PAYLOAD ACCOMMODATIONS
AVIONICS PAYLOAD SUPPORT ARCHITECTURE

JSC/SUSAN L. CREASY/HEAD, PAYLOAD SUPPORT OPERATIONS SECTION
MMAG/C.D.LEVY/ MANAGER OF HOUSTON OPERATIONS

NOVEMBER 1989

OVERVIEW

This paper addresses concepts for vehicle and payload avionics architectures for future NASA programs, including the Assured Shuttle Access program, Space Station Freedom (SSF), Shuttle-C, Advanced Manned Launch System (AMLS), and the Lunar/Mars programs. Emphasis is on the potential available to increase payload services which will be required in the future, while decreasing the operational cost/complexity by utilizing state of the art advanced avionics systems and a distributed processing architecture. Also addressed are the trade studies required to determine the optimal degree of vehicle (NASA) to payload (customer) separation and the ramifications of these decisions.

MAJOR OBJECTIVES

The avionics payload support architecture for future NASA space programs is designed to meet several major objectives. The typical customer vehicle avionics requirements include reliable provision for command, telemetry, video services, onboard data storage capability, and the capability to access vehicle data (e.g., attitude, state vehicle, timing, etc.) through some sort of "gateway". The extent and requirement for these services depends upon the type of payload (deployable, attached, scientific experiment, etc.) and the type of mission (e.g., short versus long duration). A deployable payload which only resides in the NSTS orbiter for a few hours on-orbit typically requires different services than will attached SSF scientific experiments.

From the NASA budgetary perspective, it is important to utilize an avionics payload support architecture which reduces the labor intensive integration, flight to flight reconfiguration process, mission operations support and crew/controller training.

In order to accomplish this, it is desirable to reduce the interdependence of the vehicle and payload where practical. By selectively designing the payload architecture to include a separate distributed payload data management system, including separate data storage as well as processing equipment, the payload capabilities are not limited by competition with the vehicle's requirements and the payload schedule is not tied to a mature vehicle's reconfiguration schedule. (See figure 1.) It would also be desirable to have a separate uplink and downlink capability for the same reasons as outlined above. This capability may be more of a cost impact and must be weighed as such.

An additional consideration in the design of the avionics payload support architecture is the utilization of government or industry standards such as the 80386 processor, the 1750A processor, the 1553 data bus, etc. This will enhance the budgetary aspect of the program by allowing the use of commercial off-the-shelf (COTS) hardware and software, as well as providing the customer with standards for their design and software development that match those

available on the open market. Additionally, a customer could then transition easily from host program to host program (e.g., Shuttle to Space Station Freedom) without major electronic redesign. Other benefits to this approach would be derived if the system was designed to allow provision for program interchangeability of components and the capability to easily upgrade the system as new capabilities are developed.

MAJOR MILESTONES

The concept of the use of a distributed avionics support architecture for payload applications is not a new one. It was proposed in the 1970's during the design phase for the NSTS orbiter. It was not implemented due to philosophical and budgetary considerations. As a result, the STS currently assumes an increased cost for payload reconfiguration flight to flight, does not provide sophistication in payload software control, provides minimal payload data storage capability, provides only minimal vehicle data to major payloads, and provides no vehicle avionics services to the scientific experiments flown in the middeck. In order to alleviate some of these concerns, and with the advent of the microcomputer technology, the STS is now providing customers with the option of using the STS payload and general support computer (PGSC), which is a modified GRID 1530. The STS-provided PGSC is flight qualified. Its utilization is under configuration control by the STS relative to the user interface. This insures standardization in order to reduce crew/ground training and simplify procedure development. The Interface Control Document (ICD) and user guidelines for the PGSC were published in 1989 and the system flew on STS-30 and STS-34 for the Fluids Experiment Apparatus (FEA) and Polymer Morphology (PM) payloads, respectively. Numerous other payloads have requested its use. Most notable is the Tethered Satellite System (TSS).

The PGSC does not directly have a link to the orbiter communication system which limits ground control of experiments. This, in turn, potentially limits scientific return from payloads and also places a greater burden on the flightcrew (training and timeline impact). In some applications, such as TSS, this is overcome by use of the STS smart flexible multiplexer/demultiplexer (SFMDM) which is connected to both the orbiter communications system, as well the PGSC.

Another major milestone toward the recommended payload support architecture was the original SSF payload support architecture definition. It included a distributed processing architecture, standardized testing, checkout, and training, and, in general,a decoupling of vehicle and payload services. Unfortunately, the 1989 budgetary scrub exercise resulted in the potential deletion of many of the distributed payload avionics capabilities at the Permanent Manned Configuration (PMC) such as a separate payload local area network (LAN), separate payload data storage capability, and separate payload command uplink capability. It was proposed that this configuration would be eventually upgraded with the later full-up configuration. Of concern is that the full-up configuration is not funded and will itself probably be confronted with a stringent budget. In addition, the cost and labor required to upgrade the system by the astronauts will be time consuming and complex.

The Shuttle-C payload services definition served as another milestone. Although the proposed payload services provided by the Shuttle-C are somewhat

minimal, it did propose placing the majority of the payload services responsibility on the payload customer and thus simplifying the payload integration and operations costs.

TECHNOLOGY ISSUES

Some technology issues exist for the above mentioned programs. For the STS orbiter, the issues and work that are ahead as part of the Assured Shuttle Access program include replacing certain components such as the pulse code modulator master unit (PCMMU)/payload data interleaver (PDI) due to parts obsolescence. This opens the opportunity to enhance the downlink data capability as well as provides redundancy in the payload PDI link. Cost, schedule impacts to vehicles in the flow, and compatibility with the orbiter communications system are issues being worked in this area. Another item under investigation is the replacement of the orbiter payload recorder with one more suitable to the typical payload's bit rates and data recording requirements. Another technology issue relates to the need for further advances in connector and cabling design in order to reduce both volume and weight. This is, of course, a concern with all of the programs. Another area that needs further work is to develop a capability, via modem or a separate SFMDM type "black box", to provided communication services to orbiter payloads, such as middeck scientific experiments.

The major technology issues for the SSF program, relative to avionics payload support architecture, are in the integration of existing avionics technologies to control multiple real-time systems and limited vehicle resources, such as power, communication, assets, etc.

The Lunar/Mars programs require more sophisticated avionics capabilities in order to meet the expected needs of these payloads over extended periods of time and with a greater communication lag between the ground operation team (including scientists) and the vehicle. This will lead to an increased requirement for automation and expert systems capability. In addition, it is estimated that the data storage capability required for some payloads which are proposed for the Mars mission would be on the order of 1X10E12 bytes, which is two orders of magnitude greater than what is currently available. In addition to this need for increased onboard data storage, it is anticipated that there will be a requirement for some level of pretransmission data compression for the Mars mission which has historically been a concern to the vehicle and scientific communities.

Another area which warrants further exploration for each of the NASA programs is advancement in technology to increase the operational efficiency of the above programs in areas such as automation, robotics, expert systems, voice recognition, speaker independent systems,enhanced video display capability, etc.

TRADE STUDIES

Perhaps more important than the technology issues mentioned above are the trade studies that are required to determine the NASA position relative to the payload community. The overall concern is the appropriate degree of NASA/user separation. This lies at the heart of many policy decisions relative to the handling of payloads. The question concerns the balance of

common services provided by the vehicle (NASA responsibility) versus those provided by the customer (user responsibility). For example, if the Agency were to provide an industry standard architecture (ISA) processor with display capability, an I/O consisting of MIL-STD-1553B data busses, storage medium, and access to vehicle system data via a gateway, should the Agency provide the real-time ADA operating system with the application software being the responsibility of the user? If so, what is the interface criteria between the operating system and the application programs? Where does the responsibility lie between NASA and the customer? Would NASA supply the background display structure and the customer provide the dynamic fill to reduce and minimize crew training, whether ground or flight? Is there some interface line that can be drawn between host vehicle and user responsibilities that is beneficial to both in cost and integration schedule flexibility? If this type of standardization is used (in the example), the customer can utilize relatively inexpensive ground versions of the flight hardware for software development, validation, and payload checkout. When drawing this "line", developing a policy, or developing a criteria, serious deliberation and consideration should be given to safety (i.e., when can closed loop control not be implemented by the customer), mission success, reliability and/or redundancy, minimizing crew training, integration of the cargo complement (i.e., multiple payloads), and data processing security (i.e., protection of customer proprietary information).

SUMMARY/RECOMMENDATIONS

In summary, it is important to keep in mind that the major goal of the operational NASA missions is related to payload/experiment activity, be it deployment of a satellite or a long-range scientific experiment. It is important to insure that the NASA programs provide services to make those programs, whether it is Shuttle-II, SSF, or some advanced upper stage, accessible to users. In addition, it is important for NASA to make responsible decisions in the design of its programs to insure that they have not cut costs for DDT&E, which will result in increased costs in the out-years that significantly exceed what would have been the initial DDT&E cost investment. It is time for the Agency to address commonality between programs to reduce DDT&E cost and "redesign the wheel" tendencies. It is equally important that these designs provide the user a low cost means to utilize the host vehicle capabilities without complex, time consuming integration processes, which is a major complaint of shuttle users. Program commonality and simplified integration processes with respect to payload accommodations provides the same cost and labor benefits to the customer that could be realized by NASA. Commonality provides options to the user for access to space. In simple terms, more programs and more experiments could be started, developed, and flown for the same budget, if cross program avionics commonality is imposed in the out years. However, DDT&E monies must be expended now to realize such a benefit.

In order to further pursue these areas, several things must be accomplished. Development of a payload/host vehicle policy is required to distribute responsibility, when practical and cost effective, to the user. It may be necessary to rearrange these responsibilities based on the type of host vehicle (i.e., Shuttle-II versus Shuttle-C). Whatever the result, this policy should provide a framework for avionics hardware and software

commonality between all host vehicle programs and should delineate the separation of responsibilities between host vehicle and user.

An avionics payload support architecture must then be developed to support the resultant policies. Paramount to this design is addressing standardization-use of those industry or government standards that impose program cross utilization, a means of technology evolution to resolve parts obsolescence concerns. The final system should also include functions that minimize the out years operating base, such as built in test and checkout.

It is in NASA's best interest to develop such a payload support architecture for use across programs to use new avionics technology to increase operations efficiency and thus reduce recurring operations costs.

KEY CONTACTS

Other sources of information on these areas are as follows:
Stan Blackmer/JSC/TJ2 (STS)
Bill Mallary/JSC/EH (SSF)
Ned Trahan /JSC/EH
Charlie Price /JSC/EF
C. D. Levy/MMC, Houston
Steve Elrod/MSFC (Shuttle-C)

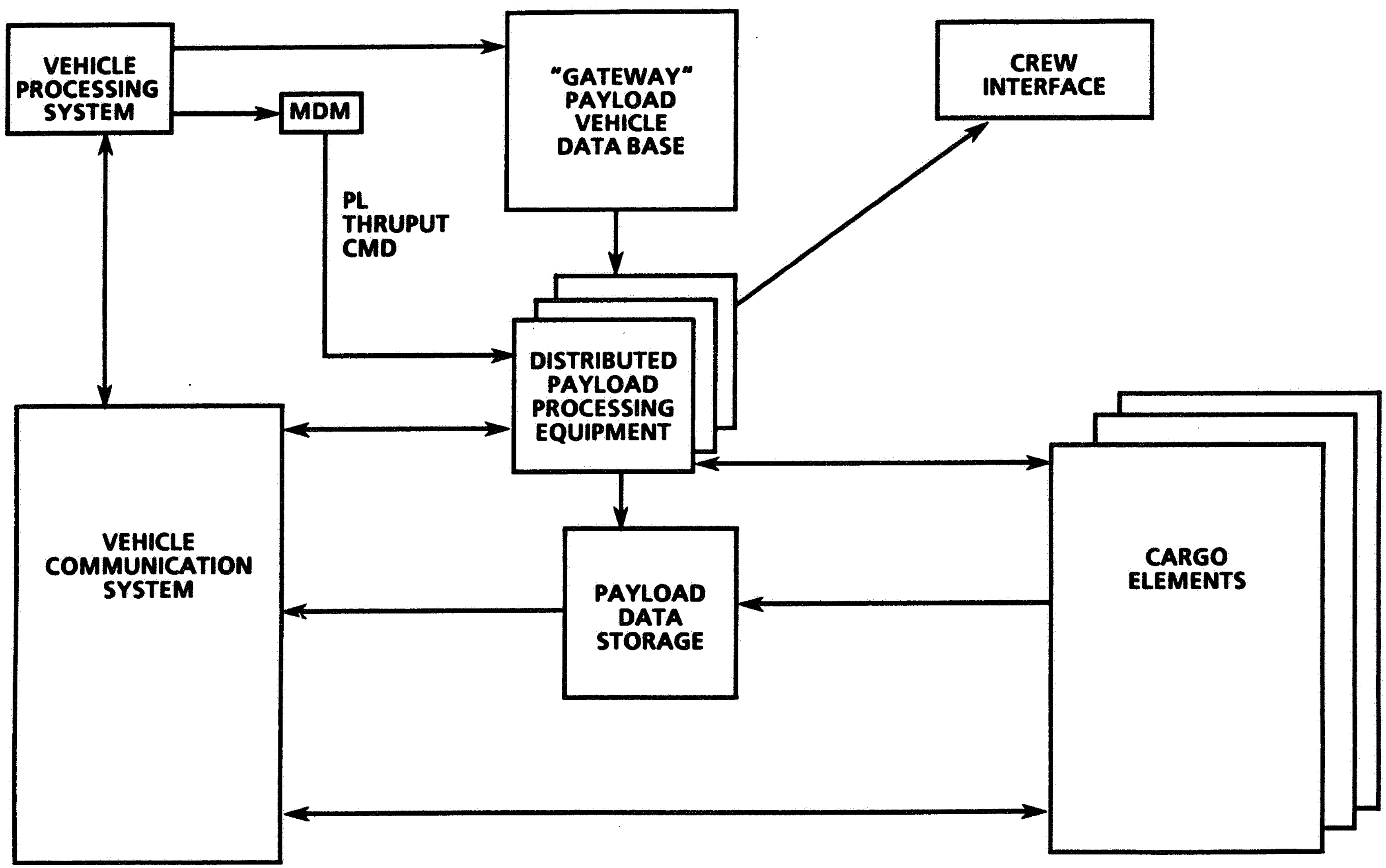

Figure. Example of a Proposed Advanced Avionics Payload Support Architecture

SATELLITE SERVICING SUPPORT

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SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM

7 - 9 NOVEMBER 1989

WILLIAMSBURG, VIRGINIA

PAYLOAD ACCOMMODATIONS

SATELLITE SERVICING SUPPORT

ROSCOE LEE
TRW DEFENSE SYSTEMS GROUP
HOUSTON, TEXAS

30 NOVEMBER 1989

PAYLOAD ACCOMMODATIONS

SATELLITE SERVICING SUPPORT

INTRODUCTION

On-orbit satellite servicing is expected to be a major focus of future U.S. space activities, with increasing emphasis on the use of unmanned vehicles and the potential for high frequency operations of manned vehicles. Such servicing will require rendezvous and docking/berthing operations by the space transportation system. These operations are currently performed manually by the flight crew in manned space transportation systems or by remote piloting for the first generation of unmanned space transportation systems. Autonomous rendezvous and docking capabilities will increase the effectiveness and availability of space transportation support of these operations.

The NASA Office of Aeronautics and Space Technology is currently funding research in technologies required for autonomous rendezvous and docking, including relative navigation sensors and guidance, navigation and control system algorithms. These technologies and their applicability to satellite servicing will be addressed. The Satellite Servicer System Flight Demonstrations, which will incorporate an autonomous rendezvous and docking capability into the Orbital Maneuvering Vehicle (OMV), are considered to be a near-term target for a subset of these technologies.

This report describes the proposed technology studies discussed at the Space Transportation Avionics Symposium in Williamsburg, VA on 7 - 9 November 1989. The discussions and findings of the Payload Accommodations Subpanel are also summarized.

OBJECTIVES

The major objective of the proposed focused technology development is to develop and demonstrate (ground and flight) autonomous rendezvous, proximity operations, and docking/berthing capabilities to support satellite servicing. It is expected that autonomous rendezvous and docking (AR&D) capabilities will benefit both the users (e.g., satellite developers and operators) and the transportation system developers and operators.

AR&D will provide increased availability of rendezvous and docking services by reducing the operational constraints associated with current capabilities. These constraints include specific lighting conditions, continuous space-to-ground communications, and lengthy ground tracking periods. AR&D will provide increased cost efficiency with the potential for reduced propellant expenditures and workloads (flight and/or ground crews). The AR&D operations will be more consistent allowing more flexibility in the design of the satellite control system and docking/berthing mechanisms.

TECHNOLOGY ISSUES

The major technology issues are the development of relative navigation sensors; development and integration of guidance, navigation and control (GN&C) algorithms and techniques; and integration of sensors, effectors, GN&C algorithms and techniques, and docking/berthing mechanisms into a total system capability. Each of these areas is discuss in more detail below.

Relative Navigation Sensor Considerations

Relative navigation sensors are required to support the operations spanning the rendezvous, proximity operations, and docking/berthing phases and is one of the major technology drivers for development of AR&D capabilities. One immediate issue is whether the technology thrust should be focused on a single sensor which spans all these phases, or a sensor suite, with various components supporting the different phases. Another consideration is the choice of active or passive sensor systems. Active sensor systems include the installation of equipment such as transponders or reflectors on the target vehicle to support the return of RF signals or light waves being transmitted by the chaser vehicle. Passive systems would rely on optical image processing by the chaser vehicle with little, if any, support by the target vehicle. The support might be a specified target form on the target vehicle.

As a result, there are a number of options for relative navigation sensors including radars, lasers, and optical imaging systems. These options are in various states of technology development. The technology studies range from proof-of-concept demonstrations to performance enhancements, where performance includes not only accuracies, but range of operation, size, weight, and power requirements. Indeed, under Project Pathfinder, JSC is performing a sensor survey and trade study to identify candidate sensors and their characteristics.

NASA/JSC is developing a laser docking sensor, a laser radar (LADAR) and LADAR imaging system, and an optical imaging system for the identification and tracking of a target. NASA/MSFC is also developing an optical imaging system for potential application to the OMV. The European Space Agency (ESA) is planning to use the Global Positioning Satellite (GPS) system and optical sensors to support the autonomous rendezvous, proximity operations and berthing of the Man-Tended Free Flyer (MTFF).

Applications of such sensors for exploration missions, particularly Mars missions, will place a premium on ability to withstand long periods of dormancy, light weight, small size and low power demands. Most of these attributes will also benefit their application to satellite servicing support, by reducing the resource requirements to be provided by the chaser vehicle.

Trajectory Design Considerations

Increased availability and high probability of successful rendezvous and docking operations would greatly benefit users. Trajectory designs are a major influence. Trajectory designs to support satellite servicing, using AR&D, will

focus on maximizing the launch windows, minimizing operational constraints such as lighting and communications and tracking coverage, adaptability to contingencies, and safety (e.g., passive collision avoidance).

The trajectory designs will be integrated with the relative navigation sensor capabilities to accommodate the sensor field-of-view and required tracking arcs. For some sensors, lighting conditions may impact the trajectory design. Although there will be a focus on reducing the requirement for continuous communications between the orbiting spacecraft and the ground, the trajectory designs will need to address space-to-space communications coverage between the chaser and target vehicles.

The trajectories must also be designed to accommodate manual takeover, either by the flight crew in manned spacecraft or by remote pilots for unmanned vehicles. The manual intervention will at least be required to support aborts and contingencies. The requirement for completion of a failed automatic rendezvous and docking by manual means must be investigated.

Guidance, Navigation, and Control Algorithms

Navigation filters must be designed to estimate relative state (positions and velocities - translational and rotational) using outputs of the selected relative navigation sensors. The adaptability of the navigation algorithm to failed sensors must be addressed. These developments are not expected to be technology drivers, but require a integrated development process.

Guidance and targeting algorithms must be designed such that the targeted maneuvers are within the acquisition range of the relative navigation sensors. They must handle a broad spectrum of dispersions. The guidance routines must be tuned to the performance of the navigation system.

The flight control system design and its impact on proximity operations and docking/berthing are highly dependent on the configurations of the chaser and target vehicles. The configurations and types of control effectors (e.g., hot gas, cold gas, reaction wheels, control moment gyros) will impact proximity operations performance. Therefore, a generic flight control system cannot be developed for all possible spacecrafts.

The development of the flight control system must be iterated with the design of the docking/berthing mechanisms. Preliminary allocations of performance budgets can be established, but it is expected that design studies will dictate the need to modify these allocations based on maturing assessments of capabilities, cost impacts, and technical risks.

A control system moding strategy must be developed to support the docking/berthing operations. Also, the approach to damping the transients resulting from docking/berthing and assured stability of the mated configuration must be developed.

Docking Mechanisms

In general, docking/berthing mechanisms will be customized to specific vehicles and/or services. A NASA standard grapple fixture for the Shuttle Remote Manipulator System (RMS) has already been established. The OMV Program had originally planned to develop a Three-Point Docking Mechanism (TPDM) and a RMS Grapple Docking Mechanism (RGDM) to support satellite servicing by the OMV. Recent funding limits have resulted in the elimination of the development of the TPDM. However, NASA still desires to develop standard docking/berthing mechanisms, which can support satellite servicing.

The international docking study may also establish standard docking/berthing mechanism requirements. These requirements would be reflected in the AR&D development.

Systems Integration

A major effort will be required to integrate the sensor, effector, GN&C, trajectory, and mechanisms "point designs" into a total package which meets the performance requirements and accommodates dispersions and failures. It is expected that tradeoffs and iterations will be required to converge on an effective allocation of the total system performance requirements among the sensors, GN&C, and mechanisms. The evolving designs of these elements will identify cost, schedule and risk impacts, which must be accommodated.

Ground demonstrations are proposed to provide proof-of-concept and proof-of-design before commitment to development of the flight systems. The ground demonstrations will encompass the cost-effective use of engineering simulations, flat-floor simulations, and mechanisms test facilities. The benefits and costs of implementations for these various facilities must be assessed and an integrated plan for their utilization developed.

Flight demonstrations are proposed to provide proof-of-design before commitment to operational use. It is expected that the flight demonstrations will involve the Space Shuttle. A major SE&I task will be development of flight demonstration plans which make maximum use of the Shuttle while accommodating the potentially extensive integration with the NSTS Program. Flight demonstrations must take into account orbiter flight and ground crew monitoring and override capabilities.

TECHNOLOGY DEVELOPMENT APPROACH

It is proposed that a work breakdown structure patterned after the Pathfinder AR&D Project be used to focus the AR&D technology development to support satellite servicing. This WBS is shown in Figure 1.

Also, it is proposed that the AR&D development for satellite servicing be aligned with the proposed Satellite Servicer System Flight Demonstrations. The Orbital Maneuvering Vehicle (OMV) will be used as the chaser vehicle. Sensor options would be evaluated through a series of staged flight demonstrations of AR&D capabilities. The target vehicle will be one of opportunity. The Orbiter will

provide the orbital delivery of the OMV and target vehicle and provide the base for flight crew monitoring and supervision of the flight demonstrations.

SYSTEMS INTEGRATION	GN&C DEVELOPMENT	SENSORS & MECHANISMS
- SYSTEM REQUIREMENTS DEFINITION	- RELATIVE GUIDANCE	- RELATIVE NAVIGATION SENSORS
- TRAJECTORY CONTROL RQMTS DEFINITION	- AUTOMATIC PROXIMITY OPERATIONS	- SENSOR TRADES
- SCENARIO ASSESSMENT	- COOPERATIVE CONTROL	- MECHANISMS APPLICATION
- PROGRAM PLANNING	- ARTIFICIAL INTELLIGENCE APPLICATIONS	

Figure 1. AR&D Work Breakdown Structure

MAJOR MILESTONES

A top-level definition of milestones was established for technology development and demonstration of AR&D capabilities to support satellite servicing. These milestones cover the period from CY 1990 through CY 1995.

0 Define AR&D system requirements - 1991

0 Develop sensor breadboard(s) - 1991

0 Develop validated GN&C software - 1992

0 Develop preliminary docking mechanism - 1992

0 Implement ground demonstration(s) - Late 1992

0 Develop plans for flight demonstrations - 1993

0 Integrate and implement Satellite Servicer System (SSS) AR&D demonstration flights

- o Demonstration Flight 1 - Late 1993
- o Demonstration Flight 3 - 1995

CANDIDATE PROGRAMS

An assessment was made of programs which might benefit from the development of AR&D capabilities. The near-term focus will be on the Satellite Servicer System Flight Demonstrations.

Lunar and Mars exploration will definitely require AR&D capabilities for unmanned vehicle operations to overcome the signal delays and communications blockages, which preclude effective remote control. Manned Mars missions can benefit from AR&D because flight crew proficiency will be degraded by the long mission durations.

It is expected that future logistics support and orbital operations of the Space Station will involve unmanned transportation vehicles and high frequency operations of manned vehicles. AR&D will allow cost effective operations from the standpoint of resources, man power, and time lines.

The Shuttle Evolution, Assured Shuttle Availability, and Next Manned Transportation System Programs will emphasize user support for orbital operations. AR&D will be a significant enhancing technology for these orbital operations.

MAJOR ACCOMPLISHMENTS

Although there has not been a specific technology program focused on development of AR&D capabilities for satellite servicing, a number of technology studies are under way, which are directly applicable.

NASA/JSC is funding the development of laser docking sensors and optical sensors. One of the laser docking sensors was originally manifested for a flight test on an Orbiter flight, but has recently been reassigned to the Satellite Servicer System Flight Demonstration. An optical sensor is currently under development by NASA/MSFC and is being demonstrated in their ground test facilities.

The AR&D Project under the Pathfinder Program has been under way for nine months. A detailed project plan, mission scenarios, and preliminary system requirements have been developed. GN&C algorithm development, a sensor trade study, trajectory designs, and basic research in mechanisms are under way.

The release of Request for Proposals for the Satellite Servicer System Phase B Study is imminent. The development of the Orbital Maneuvering Vehicle is in progress. A standard NSTS grapple fixture has been established and the Satellite Services System Working Group is sponsoring the development of standard docking and grapple mechanisms. NASA is participating in an International Docking Study to explore the potential for standard docking mechanisms across international space elements.

FACILITIES

The facilities to be used in the development of AR&D capabilities include six and twelve degree-of-freedom engineering simulations, which currently exist at various NASA centers and contractors. No major new simulations are proposed. The significant effort will be the incorporation of pertinent hardware models and applications software into these simulations.

Flat-floor facilities exist at JSC and MSFC which would allow limited ground demonstrations of AR&D capabilities with some true degrees of dynamic motion. No major upgrades to the basic facilities are anticipated. However, installation of the AR&D-unique hardware, hardware emulators, or math models will be required in these facilities.

Thermal/Vacuum facilities exist at JSC and MSFC to provide environmental testing of AR&D components, including sensors and mechanisms. No upgrades are required for these facilities to accommodate the AR&D elements.

Docking mechanism test facilities exist at JSC and MSFC. These hydraulically actuated systems will allow the ground demonstration of docking/berthing mechanisms associated with satellite servicing. No upgrades are expected for these facilities. However, the unique mechanisms must be provided to these labs.

KEY CONTACTS

The following NASA personnel are currently involved with the development of technologies which are applicable to AR&D capabilities.

<u>NASA/JSC:</u>

- o Steve Lamkin, Pathfinder AR&D Project Manager
- o Charles Gott, Trajectory Control Analysis
- o Robert Savely, Artificial Intelligence Development

<u>NASA/MSFC:</u>

- o Tom Bryan, Autonomous Rendezvous and Docking Development
- o Richard Dabney, OMV
- o Ricky Howard, Flight Robotics
- o E. C. Smith

MAJOR FINDINGS/RECOMMENDATIONS FROM STATS PAYLOAD ACCOMMODATION SUBPANEL

Following the briefings to the Subpanel, the participants were requested to identify the technology "holes" in their areas and to correlate the ability of the proposed technologies to meet a set of prescribed "needs." The following provides a compilation of the material provided to the Subpanel chairmen, who condensed these inputs into a composite Subpanel summary for subsequent presentation at the closing plenary session.

Payload Accommodation Technology Holes

- Autonomous Rendezvous and Docking Capabilities
- Systems engineering to develop design and test requirements for AR&D matched to user/mission needs
- Potential commonality in hardware, software, and trajectory requirements
- Low-cost flight demonstrations
- Independent assess of applicable DoD technologies
- Identification of other operations which can use AR&D technologies (e.g., assembly, berthing)
- Assessment of benefits and impacts of AR&D capabilities in ongoing systems (e.g., Orbiter, Orbiter RMS, OMV, Space Station).

Correlation of AR&D Technology to "Needs"

- Increased Reliability
  - AR&D provides increased consistency of proximity operations
- Increased Safety
  - Provides local control versus remote control
  - Use real-time, full-state information
- Decrease Operational Costs
  - Will generally decrease operational costs, but the extent will be proportional to the level of trust vested in the autonomous system
  - Reduces the current operational constraints (e.g., ground tracking coverage, communications coverage periods, lighting conditions) resulting in increased availability of rendezvous and docking services.
  - Reduces resource requirements (e.g., propellant and crew time - flight and ground)
- Lower Hardware Costs
  - Reduces mechanisms costs because of lower contact dynamics
- Increased Robustness/Flexibility
  - Allows more operational flexibility
  - Is adaptable to off-nominal conditions.

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530704
6p

PRESENTATION 3.3.4

N91-17048

PAYLOAD DEPLOYMENT SYSTEMS AND ADVANCED MANIPULATORS

PAYLOAD DEPLOYMENT SYSTEMS AND ADVANCED MANIPULATORS

This paper presents the results of discussions on future development of avionics to support payload deployment systems and advanced manipulators. The discussions summarized here were held during the Space Transportation Avionics Technology Symposium in Willaimsburg, Virginia on Nov 7-9, 1989.

The quad charts for this subtopic were generated by C. Gott, D. Homan, and E. Bains/NASA-JSC, P. Swaim/MDSSC, and R. Haken/TRW. During the symposium significant contributions were also made by C. Price/NASA-JSC and M. White/RI-D.

Symposium partiucipants agreed that this subpanel would have benefited from more participation by users. It was suggested that inputs from Shuttle payload users should be incorporated, either by direct discussions with users or by incorporating comments from users as kept by Payload Accomodations. JPL, Goddard, and Langley, as builders of payloads, and the Space Station Utilization Office could also provide useful inputs. Other potential users for future systems should also be identified as early as possible to determine what they anticipate their needs to be.

Symposium participants also recognized that payload deployment is normally not a safety critical area, and as such, is vulnerable to budget cuts that defer costs from development to operations. This does give opportunities for upgrades of operational systems, but these must be very cost effective to compete with vehicle requirements that enhance safety or increase lifetime.

The quad charts prepared for the symposium are shown in Figures 1 and 2. These present progress and needs in five major areas. These are (1) Fault tolerance and redundancy management; (2) Hardware upgrades to increase longeviety; (3) Development of basic capability for future systems; (4) Improvements to enhance crew effectiveness/autonomous operations; and (5) Enhancements that decrease sensitivity of the base vehicle to manipulator operations.

The quad charts showed improved redundancy/ fault tolerance as a major objective for payload deployment systems. Discussion at the symposium identified this as a major need for the Shuttle RMS, but one that is not in work at present. Redundancy management as applied to the Shuttle GN&C is considered desirable for use with SRMS, but there is no activity in this area at present. In addition, no future programs were identified as having active programs to incorporate redundancy management into their designs; adding this to the SRMS would be likely to bring it into future programs also.

Hardware upgrades that could reduce stress on the manipulator were also considered a major source of system lifetime

improvement. While most hardware changes to manipulators may not be in the area of avionics, load sensing/relief is an active and potentially valuable avionics upgrade. A load sensor for the SRMS is currently under development by JPL, and successful demonstation of this capability would provide a valuable leadin for future ssystems. This capability would be extremely valuable for autonomous systems such as would be needed for unmanned flights to Mars.

The third area, development of basic capability for future systems, has a great deal of activity for space station, but very little activity for other future systems. Space station work has included development and evaluation of manipulator control laws, and future work is anticpated to include path planning algorithms, collision avoidance algorithms, and control for more than one manipulator in parallel operation. While there is virtually no active work for future systems other than space station, the requirements for those systems must also be defined. The existing shuttle RMS software and the space station work, both that currently being done and that being planned, provide a solid base for other systems when requirements become firm.

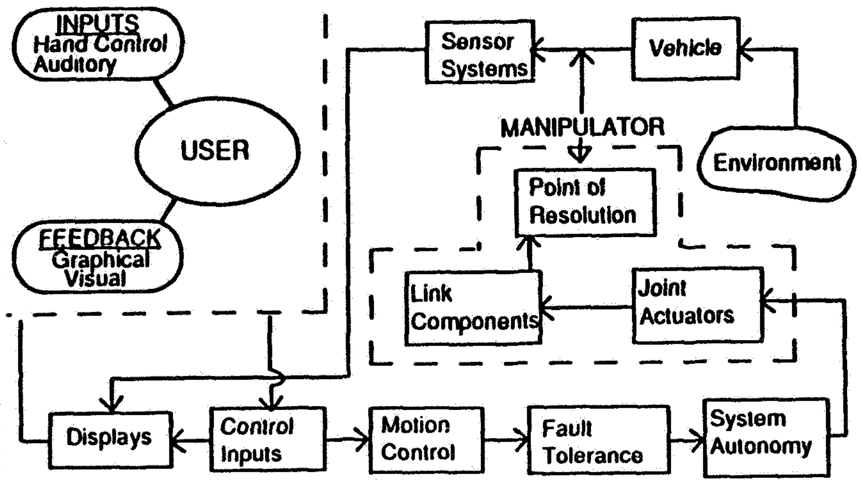
Many improvements to enhance crew effectiveness or to support autonomous operations were suggested. The quad charts identified path planning and collision avoidance as reducing training requirements and on-orbit planning. Collision avoidance was also mentioned in discussion as a requirement for systems operating outside a fixed work cell, particularly with multi-arm operations. Improvements in information display were also discussed, and were agreed to have high potential payback. EVA requirements could be greatly reduced with dexterous handling, but this has a high initial cost that may make it hard to sell. Areas that have already shown major accomplishments in enhancing crew effectiveness in ground tests include helmet mounted displays and stereoscopic vision systems. Other systems that were mentioned during symposium discussions as having potential for great benefit without great cost included control of cameras by voice or by automatic tracking of a selected point such as the End Effector.

Finally, pre-mission planning of base vehicle control could be made a great deal simpler and cheaper by reducing the response of the base vehicle to manipulator operations. Changes to the Shuttle on-orbit DAP have already been approved to improve vehicle control during SRMS operations, and further improvements are possible. This area is also under active investigation for space station. The need and benefits from this activity seem clearly established.

In summary, redundancy management for the shuttle RMS was mentioned as a major need that is not currently being addressed. For future systems, collision avoidance, simpler user interface with manipulators, and incorporation of force feedback systems were mentioned as major areas needing work.

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
PAYLOAD ACCOMMODATION
P/L DEPLOY SYSTEMS & ADV. MANIPULATORS

P/L DEPLOYMENT SYSTEMS & ADV MANIPULATORS



MAJOR OBJECTIVES:

- Reduce pre-mission planning
  - Improved redundancy / fault tolerance
  - Optimal path planning
- Increase crew productivity
  - Autonomous operations frees crew for other tasks
  - Path planning / collision avoidance reduces training requirements and on-orbit planning
  - Dexterous handling reduces EVA requirements
- Increase hardware longevity
  - Load sensing / relief reduces joint / structural loads
- Reduce base vehicle attitude control system sensitivity to manipulator operations

KEY CONTACTS:

C. Gott /JSC/ FM8

D. Homan / JSC / FM8

E. Bains / JSC / EH23

J. Davidson / MMC

FACILITIES:

- Integrated Graphics and Operations Analysis Laboratory (IGOAL)
- Draper Remote Manipulator System Simulation (DRS)

MAJOR MILESTONES (1990 - 1995)

- Major programs to support
  - NSTS
  - Space Station Freedom
  - Lunar Base / Mars Mission Scenarios
- Programmatic Issues
  - Manipulator design and operations requirements
  - Integrate vehicle / manipulator control system design
  - Vehicle assembly and on-orbit processing
  - Lunar base construction
  - Mars surface operations
- Simulation development for state-of-the-art hardware & software
  - Kinematic
  - Dynamic
- Evaluate advanced technologies
- Develop systems concepts
- Evaluate capabilities / cost / benefits

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
PAYLOAD ACCOMMODATION
P/L DEPLOY SYSTEMS & ADV. MANIPULATORS

TECHNOLOGY ISSUES:

- Planning and Control Algorithm Development
  - Path planning
  - Collision avoidance
  - Redundant manipulator control
- Sensor / Effector technology
  - Dexterous manipulators / force feedback systems
  - Robotic vision / tracking
- Interaction of deployment device with vehicle control
- System performance
- System reliability

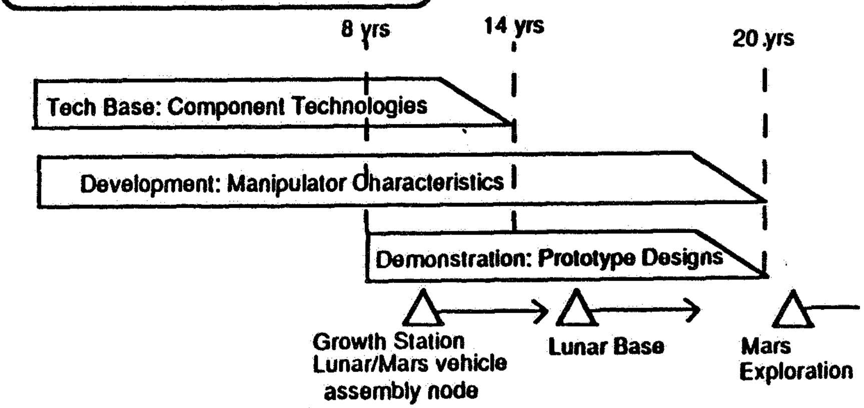
CANDIDATE PROGRAMS:

- Shuttle Remote Manipulator System
- Flight Telerobotic Servicer
- OMV
- Lunar Base
- Mars exploration
- EVA Retriever
- Special Purpose Dexterous Manipulator SPDM
- Mobile Servicing Centre

MAJOR ACCOMPLISHMENTS:

- Development of kinematic and dynamic simulators for generic remote manipulator systems and vehicle interaction
- Manipulator control law development and evaluation
- Telepresence systems technology investigations
  - Helmet mounted display
  - Stereoscopic vision systems
- Man-in-the-loop part task simulators
  - Shuttle Remote Manipulator System
  - Space Station Remote Manipulator System
  - Flight Telerobotic Servicer

SIGNIFICANT MILESTONES:



- Component technologies make up total manipulator system
- Robotic characteristics enhance manipulator operation and performance
- Prototype designs evolve over several generations

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12p

PRESENTATION 3.3.5

N91-17049

ADVANCED TELEMETRY SYSTEMS FOR PA TECH. NEEDS, OBJECTIVES & ISSUES

ADVANCED TELEMETRY SYSTEMS FOR PAYLOADS
TECHNOLOGY NEEDS, OBJECTIVES & ISSUES: A WHITE PAPER

Introduction

Payloads refer to systems and users in space. They are usually launched or carried by a space transportation system but are not in any way a functional part of the transportation system. Unmanned spacecrafts, specifically come under this category.

There are two kinds of payloads, those which remain "attached" to the transportation system and those which are separated and become "detached". Detached payloads are transported to geosynchronous or other Earth orbits, placed on deep space trajectories or simply operate (free flyers) in co-orbit. The attached payloads are usually serviced via hardwire links while detached payloads use RF channels. Attached payloads communicate to ground terminals generally via the space transportation system(STS). The STS provides for transmission of data from these payloads, by providing standard or non-standard on board equipment. Standard accomodations usually meets all the user standard data requirements, and provides maximum flexibility and reliability, minimum cost and minimum concern for the services. A non-standard accomodation deviaties from the standard equipment requiring special equipment for a specific payload.

In terms of services to users, functional links to payloads consist of command and low rate telemetry for the forward link, and high rate telemetry (and/or video) for the return link. The return link, usually a high data rate continuous information transmission, requires special processing at suitable nodes of the network path (from the source in the payload to the sink on the ground).

Currently the NASA Space Transportation System supports standard and non-standard users both in 'attached' and 'detached' payload configurations. Onboard avionics supporting the standard user in

each category provides onboard processing of the telemetry data while the non-standard users either process the data to comply with standard interface requirements, or non-standard data is routed by the STS unprocessed in a 'bentpipe' mode.

With the growth in the number of users (spacecraft payloads) and the deployment of new facilities in space, the existing scenario for payload telemetry systems will be impacted. Higher data rates will need to be telemetered on the ground in some flexible format. In many cases a near real-time data reception will be required. How can advanced avionics technologies solve the real space transportation problems of payload telemetry? Namely, support the higher data rates, provide a near real-time data on the ground, and reduce the cost of payload accomodation.

Advanced payload telemetry system development should be focused in the following areas; bulk data transmission, distributed processing, use of networking methods and application of intelligent systems technology. Higher reliability and efficiency are additional concerns for advanced technologies. The development of these technologies are interdependent; for example, bulk data transmission will utilize applications of distributed processing, artificial intelligence technology, and networking methods to achieve higher throughput and efficiency.

Technology Needs, Objectives and Issues

Advanced technologies currently identified for support of the STS payload telemetry system include the following;

1. Integrated data systems
2. Intelligent system approach
3. Advanced signal processing
4. Payload interface technology
5. Data distribution processing
6. Information compression
7. Voice and data encryption

8. Mass data storage and retrieval
and
9. Advanced modulation and coding.

The current trend in the development of advanced technologies is to integrate all types of data (voice, text, data, graphics and video) such that the signals appear 'alike' to the transmission channel. Such an approach provides commonality of processing, particularly at the intermediate transmission nodes. It also provides transparent communication as far as the end-to-end channel is concerned.

Recent developments in the practical artificial intelligence(AI) hardware/software such as expert systems and artificial neural networks show great promise for advanced telemetry applications. AI concepts for data compression/selection are already being implemented in new designs. Raw sensor data is subjected to 'intelligent conditioning' to help reduce the data volume and to monitor key trends in data changes. Knowledge enhancement/ adaptive sensor techniques are being successfully applied in telemetry systems. Natural user interfaces are similarly upgraded on these lines. The AI concepts are generally implemented as a part of 'embedded' software/hardware architecture. Fault diagnosis applications have become very common. Neural net applications in text/graphic and video are gaining grounds. Reliability of such systems for unsupervised operation is not well established but the systems currently show a great potential in supervised or operator-intensive operation. In cases where intensive decision-making is involved, speed of operation is questionable for real-time operations. A real-time integration issue to be addressed in an intelligent systems approach is an intervention by the operator in a situation where a human life is in danger.

Advanced signal processing refers to implementing standard as well as new innovative algorithms in higher speed technologies to cope with higher mass of data. Both the data compression and data

integration techniques are involved. Data compression is used to remove the redundancy in the source information and save for transmission only the information that is unknown. Data integration refers to the need to 'translate' various kinds of source data-- voice, computer data, video, graphics, etc --into a common data type that will respond to the rigors of channel transmission. The key issue in the signal processing implementation, building a standard architecture for the high-speed digital signal processor, has been solved. Several 'common' signal processors based on variations of common architectures for DOD standard avionics high-speed signal processors (parallel pipeline processing architecture) have been designed by vendors such as IBM, Hughes, AT&T, and Northrup. These are characterized by modular design, standard interconnection backplane, test/maintenance bus, data transfer network, etc. They provide processing of feature extractions, images and signatures, and have global memory elements. The state-of-the-art, i.e., vector quantization for images, LPC for voice, etc., appear adequate for the need as most of the hardware is available to implement real-time operation in a space-qualified environment. AI technology of neural networks is being applied to the data analysis tasks successfully.

Payload interface technology is yet another area which is being developed. The effort is to design a standard interface such that the system is easily reconfigurable. Interface parameters include data and clock rates and mode of transfer at the physical interfaces. Protocols for data transfers and provisions for standard user interfaces for log-on, dial-up, or menu/selection tree (user-friendly), have been developed. AI techniques will find good applications in interface reconfiguration.

The payload telemetry system should be capable of routine extraction/ formatting/manipulation of user data and user data monitoring, for example, histogrammming, plotting, spectral transforms, etc. These services, if offered, may involve special data protocols, data rates, and link services (full duplex, half duplex, etc). An economic as well as technical issue will be involved in the

partitioning between onboard, and distributed processing. The level of processing by the user, on the ground and onboard at different transmission nodes will provide a variety of burdens for both the user and the space transportation system. For efficient distribution, advanced higher speed multiplexers and statistical concentrator algorithms will be employed. Network technology to move the data around efficiently will be used. The use of fiber optics for internal networking and distribution is well recognized.

In order to have an effective handle on the data flow from/to the payload, the size of the payload data traffic should be reduced by an efficient lossless compression. Straight forward data compression of channel bit rate will be clearly desirable, but there will probably also be a clear trend for analyzed data only, with temporary backup storage and transmission of stored data. This information compression processing involves new approaches to noiseless coding (LPC/vector quantization extension) and provision for signal transformation, statistical analysis, and efficient presentation formats.

The space transportation system environment will be used by a variety of common authorized users with at least indirect access to the total transmission media. Therefore some degree of privacy (e.g. encryption of virtual channels) will be required wherein users will be able to utilize only the data specifically addressed to them, even though they may be able to access the entire multiplexed data stream contained on the transmission media. The virtual channel between the payload and the ground, which is independent of actual routing path, will facilitate privacy. In theory, the technology to assure privacy is available today. The data encryption standard (DES) for commercial activities is sufficient for protection against all except concerted attack. However, three issues need consideration. The first issue is speed of operation. Operation of encryption technology at very high data rates is yet to be developed. The second issue is the key distribution problem similar to computer access passwords today. Standards provide ways of implementing/managing keys with

varying levels of privacy assurances, but implementing a uniform system-wide management strategy will be difficult. In a large multiport, multimode environment, the assurance mechanism that keeps keys up-to-date and properly distributed will not be a simple task. A possible AI application may be inevitable. The third issue is the interaction of the encryption mechanism with the channel error coding and addressing (routing) protocols. The transmission medium must have either unencrypted or commonly encrypted routing information to properly forward data via the designated virtual channel. Further, the encryption mechanism is useless if it cannot cope with the reality that the channel will itself provide corrupted data to the end user.

With the growth of the payload data, mass data storage and retrieval will become very important. The data will probably be stored on optical disks with very high read/write rates and will have up to tera-byte capacity. With such a large quantity, a provision for fast retrieval of data will be needed. An intelligent data base that can provide resource management, allocate services to competing users and interface with the ground user to set up comunications, will become part of the system.

The objective of advanced modulation and coding is to provide improved system performance in terms of increased bandwidth and power efficiency while minimizing transmission errors and the effects of interference. New techniques that combine both the modulation and coding are being developed. Quadrature amplitude modulation (QAM) is a digital modulation scheme designed for a ground based microwave telephone link to provide premium bandwidth conservation. Trellis modulation (TCM), by virtue of adding the error-correction code as part of the modulation, is a prime candidate for high data rate transmission. Other schemes based on spectrum, spreading such as CDMA and FH provide interference immunity. They are also characterized by slowly degrading performance as the signal to noise ratio is reduced. It is also likely that synchronization will be an issue for the advanced modulation

scheme. Parallel processing architectures are being evolved to handle the high data rates.

Conclusion

The current trends in advanced payload telemetry are the new developments in advanced modulation/coding, the applications of 'intelligent' techniques, data distribution processing, and advanced signal processing methodologies. Concerted efforts will be required to design ultra reliable man-rated software to cope with these applications. The 'intelligence' embedded and distributed throughout various segments of the telemetry system will need to be overridden by an operator in case of life-threatening situations, making it a real-time integration issue. Suitable MIL standards on physical interfaces and protocols will be adopted to suit the payload telemetry system. New technologies and techniques will be developed for fast retrieval of mass data.

Currently, these technology issues are being addressed to provide more efficient, reliable, and reconfigurable systems. There is a need, however, to change the operation culture. The current role of NASA as a leader in developing all the new innovative hardware should be altered to save both time and money. We should use all the available hardware/ software developed by the industry and use the existing standards such as FDDI, ISO/OSI, STDN, rather than inventing our own.

SYSTEMS ENGINEERING & INTEGRATION (SE&I)

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12P

PRESENTATION 3.4.1

N91-17050

AVIONICS ADVANCED DEVELOPMENT STRATEGY

AVIONICS ADVANCED DEVELOPMENT STRATEGY

D. DYER NASA HQ/RESTON

INTRODUCTION

THIS PAPER IS CONCERNED WITH THE PROBLEM OF HOW TO PUT TOGETHER AN INTEGRATED, PHASED, AND AFFORDABLE AVIONICS ADVANCED DEVELOPMENT PROGRAM THAT LINKS AND APPLIES TO OPERATIONAL, EVOLVING, AND DEVELOPING PROGRAMS/VEHICLES, AS-WELL-AS THOSE IN THE PLANNING PHASES. COLLECTING TECHNOLOGY NEEDS FROM INDIVIDUAL PROGRAMS/VEHICLES AND PROPOSED TECHNOLOGY ITEMS FROM INDIVIDUAL DEVELOPERS USUALLY RESULTS IN A MISMATCH AND SOMETHING THAT IS UNAFFORDABLE. A STRATEGY TO ADDRESS THIS PROBLEM WILL BE OUTLINED WITH TASK DEFINITIONS WHICH WILL LEAD TO AVIONICS ADVANCED DEVELOPMENT ITEMS THAT WILL FIT WITHIN AN OVERALL FRAMEWORK, PRIORITIZED TO SUPPORT BUDGETING, AND SUPPORT THE SCOPE OF NASA SPACE TRANSPORTATIONS NEEDS.

SCOPE OF NASA SPACE TRANSPORTATION

THE SCOPE OF SPACE TRANSPORTATION SYSTEMS UNDER CONSIDERATION CAN BE GROUPED BY MAJOR FUNCTIONAL AREAS: CARGO TO LOW-EARTH-ORBIT (LEO), CARGO AND PEOPLE TO LEO AND RETURN TO EARTH, ON-ORBIT TRANSPORTATION AND SERVICES, PEOPLE RESCUE, LEO FACILITY, AND MARS EXPLORATION. THESE ARE SHOWN IN FIGURE 1; ALONG WITH THE VEHICLES WITHIN THOSE AREAS AND THEIR DEGREES OF MATURITY. VERY FEW ARE OPERATIONAL, WITH SOME IN

PHASE C/D DEVELOPMENT, BUT MOST ARE IN PRELIMINARY DEFINITION PHASES. THESE MAJOR FUNCTIONAL AREAS WILL BE REQUIRED TO SUPPORT NASA PROGRAMMATIC GOALS FOR AT LEAST THE NEXT 20 YEARS AND PROBABLY LONGER. THEREFORE, UPGRADING AND EVOLVING EXISTING VEHICLES AND CAPABILITIES BECOMES AN ADDED DIMENSION TO DEFINING, BUILDING AND PHASING IN NEW VEHICLES AND CAPABILITIES.

MANY STUDIES ARE UNDERWAY WITHIN THESE FUNCTIONAL AREAS TO INVESTIGATE OPTIONS CONCERNING UPGRADING AND EVOLVING EXISTING CAPABILITIES, AUGMENTING WITH NEW CAPABILITIES AND/OR STARTING OVER WITH A "CLEAN SHEET" DESIGN. FOR EXAMPLE THE NEXT MANNED TRANSPORTATION STUDY HAS COMPLETED PHASE I WHICH LOOKED AT TRANSPORTATION ARCHITECTURAL OPTIONS ASSOCIATED WITH THE CARGO TO LEO AND CARGO AND PEOPLE TO LEO AND RETURN TO GROUND FUNCTIONAL AREAS. THIS STUDY IS PLANNED TO CONTINUE INTO PHASE II WITH MORE DETAILED DEFINITION AND COSTING STUDIES. IN THE AREAS OF ON-ORBIT TRANSPORTATION AND SERVICES ADDITIONAL STUDIES WILL BE/ARE BEING MADE TO UNDERSTAND THE EVOLUTION OF THE OMV, DEFINITION OF THE OTV, ROBOTIC SERVICER, PLATFORMS, AND FREE FLYERS. THE SPACE STATION (LEO FACILITY) IS NOT A TRANSPORTATION VEHICLE PER SE BUT IS A VITAL PART OF THE TOTAL SPACE TRANSPORTATION PICTURE IN THAT SIGNIFICANT REQUIREMENTS ARE PLACED ON OTHER TRANSPORTATION FUNCTIONAL AREAS BY IT AND IT CAN ALSO BE A JUMPING OFF POINT (TRANSPORTATION NODE) FOR VARIOUS MARS EXPLORATION SCENARIOS. SPACE STATION EVOLUTION STUDIES ARE IN PROGRESS.

EXPLORATION STUDIES ARE UNDERWAY TO

DEFINE TECHNICAL AND PLANNING INFORMATION AND SHOULD BE AVAILABLE IN EARLY 1990. WHILE VARIOUS ASPECTS AND RELATIONSHIPS ACROSS THE FUNCTIONAL AREAS ARE CONSIDERED DURING THESE STUDIES, AN END-TO END ASSESSMENT AND DEFINITION IS REQUIRED TO UNDERSTAND AND DERIVE AN INTEGRATED AND PHASED SET OF AVIONICS ADVANCED DEVELOPMENT NEEDS.

STRATEGY DEVELOPMENT

THIS TOP DOWN APPROACH TO DEFINING AN AVIONICS ADVANCED DEVELOPMENT PROGRAM INVOLVES SEVERAL STEPS: DEFINING PROGRAMMATIC GOALS AND REQUIREMENTS, PERFORMING ASSESSMENTS, DERIVING AVIONICS TECHNOLOGY NEEDS, ESTABLISHING SELECTION CRITERIA, AND APPLYING THE CRITERIA TO PROPOSED TECHNOLOGY DEVELOPMENTS.

THE PROPOSED STRATEGY DEVELOPMENT WOULD BEGIN WITH THE COLLECTION OF CANDIDATE/PROPOSED SPACE TRANSPORTATION SYSTEMS, CONCEPTS, AND SCENARIOS AS DEFINED BY THE ABOVE MENTIONED STUDIES. ESTABLISHMENT OF NASA PROGRAMMATIC/USER NEEDS, PRIORITIES, AND SCHEDULES: FIRST, THOSE ASSUMED WITHIN EACH STUDY, AND SECOND, THOSE WHICH WOULD APPLY ACROSS FUNCTIONAL AREAS WOULD BE THE SECOND TASK. THE NEXT TASK WOULD INVOLVE AN ASSESSMENT OF MIXED FLEET OPERATIONS ACROSS ALL FUNCTIONAL AREAS TO DETERMINE ALTERNATE VEHICLE STRATEGIES AND SYNERGISTIC FLEET CAPABILITIES. WITH THE MIXED FLEET OPERATIONS UNDERSTOOD, THE VEHICLE, SYSTEM, AND OPERATIONS

DDT&E DRIVERS AND PRIORITIES CAN BE DEFINED. THE NEXT STEP IS TO CORRELATE THE DDT&E DRIVERS TO AVIONICS TECHNOLOGY DRIVERS.

THE PAYBACKS AND RISKS OF EACH OF THESE DRIVERS SHOULD BE EVALUATED AND UNDERSTOOD. WITH THIS COMPOSITE SET OF DATA AND INFORMATION THE ESTABLISHMENT OF A SET OF TECHNOLOGY SELECTION AND EVALUATION CRITERIA BECOMES THE NEXT TASK. THIS CRITERIA COULD INVOLVE MANY PARAMETERS SUCH AS; TIMING, FLIGHT TEST REQUIREMENTS, GREATEST PAYBACK ACROSS FUNCTIONAL AREAS, ETC.

SOME OF THE AVIONICS TECHNOLOGY DRIVERS CAN BE GROUPED ACCORDING TO THEIR TIME PHASED SUPPORT TO SEVERAL PROGRAMS/VEHICLES. THESE SHOULD BE IDENTIFIED AND WORKED BY ONE SOURCE OVER A LONGER PERIOD OF TIME IN A BUILD UP FASHION TO SUPPORT THE VARIOUS PROGRAMS/VEHICLES. FIGURE 2 SHOWS THREE EXAMPLES WHICH APPLY TO OPERATIONAL PROGRAMS AS-WELL-AS PLANNED PROGRAMS/VEHICLES. IF THESE TECHNOLOGIES ARE WORKED AS A FUNCTIONAL TYPE (RATHER THAN BY PROGRAM/VEHICLE) MULTIPLE START UP COSTS AND "REINVENTION OF THE WHEEL" CAN BE AVOIDED. ALSO THE FUNDING TO SUPPORT THESE TYPE EFFORTS CAN BE BUDGETED OUT OVER THE YEARS TO MATCH THE TIMING REQUIREMENTS OF THE TECHNOLOGY NEEDS.

RECOMMENDATION

EARLY IN 1990 MUCH OF THE INPUT DATA AND INFORMATION NEEDED TO INITIATE THE ABOVE TASKS WILL BE AVAILABLE. IT IS RECOMMENDED THAT A SMALL WORKING GROUP BE FORMED AND TASKED TO WORK THIS AVIONICS ADVANCED DEVELOPMENT STRATEGY. THE OBJECTIVE BEING TO

DEVELOP A FRAMEWORK FOR ASSESSING AND INTEGRATING AVIONICS ADVANCED DEVELOPMENTS WHICH WILL RESULT IN A PRIORITIZED AND PHASED DEVELOPMENT ITEMS TO SUPPORT NASA SPACE TRANSPORTATION NEEDS.

SYMPOSIUM FEEDBACK AND OBSERVATIONS

COMMENT FROM ALS: THEY ARE SKEPTICAL THAT A PRIORITIZED SET OF ADVANCED DEVELOPMENT ITEMS CAN BE DEVELOPED BASED ONLY ON TECHNICAL MERIT. ALS HAD TRIED TO DO BUT HAD RUN INTO TOO MANY POLITICAL FACTORS.

COMMENT FROM MDAC: AN ANALYTICAL TOOL EXIST THAT WILL PRIORITIZE ITEMS BASED ON VARIOUS COMBINATIONS OF WEIGHTING FACTORS.

OBSERVATIONS:

1. THE AVIONICS TECHNOLOGY NEEDS TO SUPPORT THE VARIOUS PROGRAMS/VEHICLES WERE NOT SPECIFIC OR COMPLETE ENOUGH; ESPECIALLY, FOR THE ON-ORBIT TRANSPORTATION AND SERVICES, SPACE STATION, AND LUNAR/MARS EXPLORATIONS PROGRAMS.

2. IT IS NOT CLEAR WHERE QUESTIONS THAT ARE CONCERNED WITH TRADES BETWEEN NASA HQ CODES SHOULD BE REFERRED TO. THE REQUIREMENT FOR A NASA CHIEF ENGINEER TYPE FUNCTION AT HQ WAS DISCUSSED.

ACRONYMS

ACRC - ASSURED CREW RETURN CAPABILITY

ALS - ADVANCED LAUNCH SYSTEM

AMLS - ADVANCED MANNED LAUNCH SYSTEM

CERV - CREW EMERGENCY RETURN VEHICLE

CRS - CREW RESCUE SYSTEM

CRV - CARGO RETURN VEHICLE

EDO - EXTENDED DURATION ON-ORBIT

OMV - ORBITAL MANEUVERING VEHICLE

OTV - ORBITAL TRANSFER VEHICLE

PLS - PERSONNEL LAUNCH SYSTEM

STS - SPACE TRANSPORTATION SYSTEM (SHUTTLE)

SS - SPACE STATION

SSF - SPACE STATION FREEDOM

Figure 1. Scope of Transportation Needs and Maturities

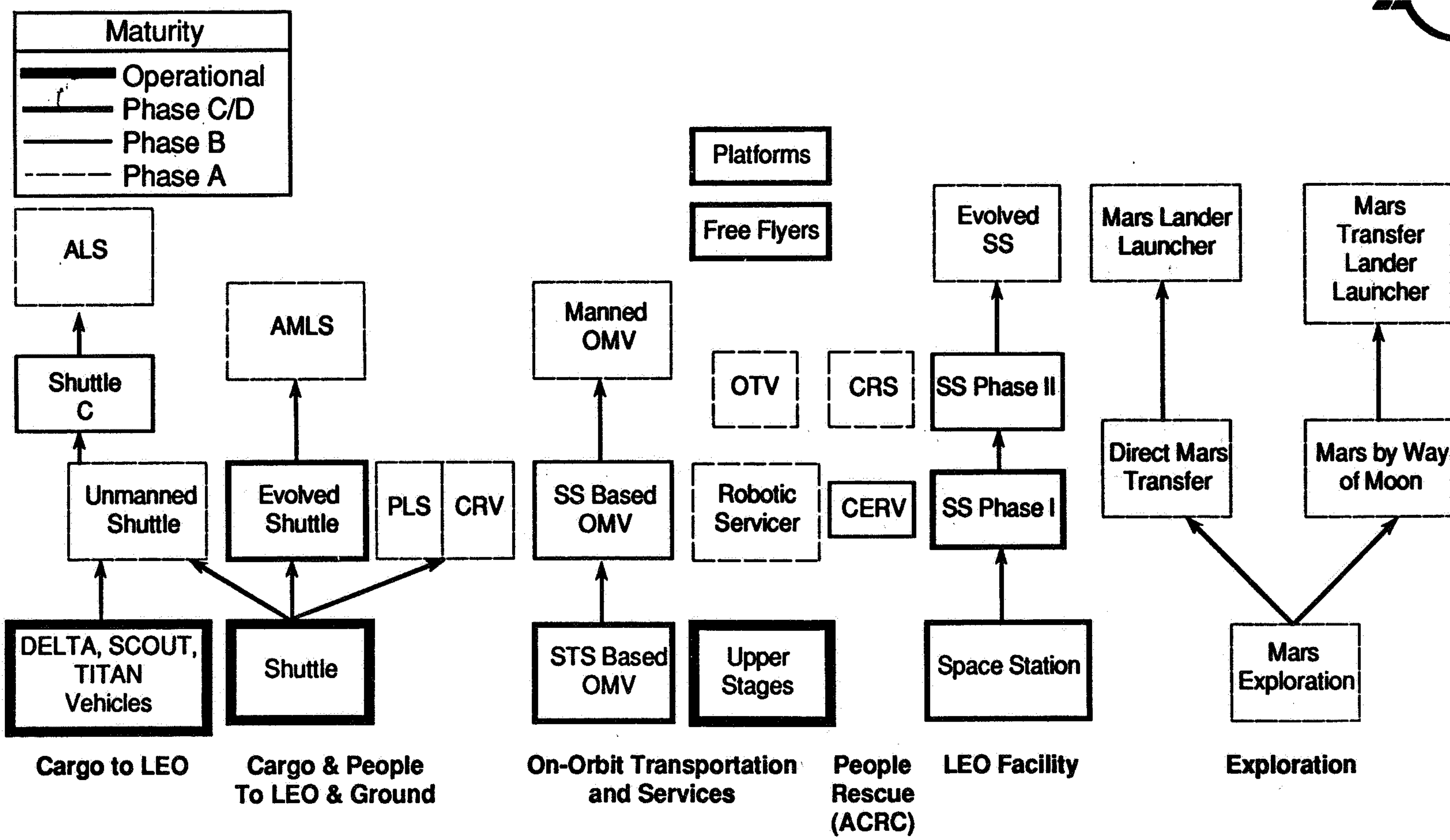

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Figure 2. Examples of Across Program Functional Types

FREEDOM

INFLIGHT MAINTAINABILITY FOR LONG DURATION MISSIONS

- NSTS - To Support Extended Duration On-orbit (EDO)
- SSF - External and internal maintenance and logistics
- CERV - Long-term dormant avionics with quick activation
- Mars Transfers - To support functional availability and redundancy

INFLIGHT CREW TRAINING

- NSTS - To support landings after an EDO
- SSF - To support Phase II and growth station operations
- Mars - To support landings after long transfer times

AUTOMATIC RENDEZVOUS AND DOCKING

- NSTS - Unmanned flights
- SSF - To support man tended free flyer return to station
  - To support OMV/platform return to station
  - To support unmanned resupply
- OMV - To support approaches to orbiter, platforms, and satellites
- Mars - To support Mars sample return mission

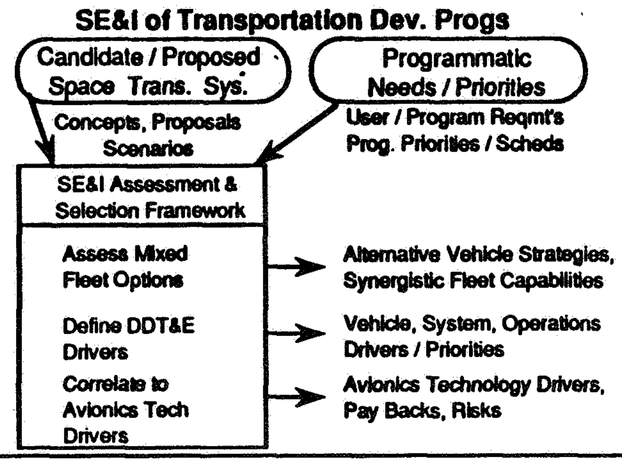
National Aeronautics and Space Administration

Space Transportation Avionics Technology Symposium
Systems Engineering and Integration
Avionics Advanced Development Strategy

November 1989

FREEDOM

Advanced Avionics Concepts



Major Objectives

Develop framework for assessing and integrating avionics advanced technology developments

- Priority and phasing of future space transportation systems
- Integration across multiple programs/projects
- Selection/Evaluation criteria

Key Contacts:

D. Dyer/NASA–Reston
K. Cox/JSC

Facilities:

Major Milestones (1990 – 1995)

- **Assimilate results/status of various transportation systems studies (Mid to late 90)**
  - Manned Space transportation
  - Lunar/Mars exploration initiative
  - Cerv, ext. duration orbiter
- **Develop initial framework for assessing/prioritizing tech. needs (mid FY 90)**
- **Apply framework (FY 91)**

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Space Transportation Avionics Technology Symposium
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Avionics Advanced Development Strategy

November 1989

FREEDOM

Technology Issues	Candidate Programs
• Integration of transportation needs • Standard, pre-declared criteria for assessing: – Fleet options – Design drivers – Technology focus • Systematic assessment of sensitivities of options & corresponding risks (Tech/Prog)	• **Manned transportation systems** – Shuttle evolution – CERV – Manned Mars/Lunar Missions • **Unmanned transportation Sys** – OMV – OTV – Mars/Lunar Missions

Major Accomplishments	Significant Milestones
• MRSR Phase B studies under way • Manned space transportation study/definition under way • Lunar/Mars exploration initiative under way	

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PRESENTATION 3.4.2

N91-17051

RISK ANALYSIS AND MANAGEMENT

RISK ANALYSIS AND MANAGEMENT

H. E. Smith
Lockheed Engineering & Sciences Company

BACKGROUND AND NEED

The complexity and life cycle of both NASA flight and ground systems have undergone a significant increase over the past generation. Additionally, the personnel who possess the design, programmatic and operational knowledge of these systems are becoming unavailable. These changes in turn have dictated the need for a methodology (Figure 1) which provides a common backbone for the forms of risk assessments and analyses which are described in NASA Management Instruction 8070.4, "Risk Management Policy for NASA Manned Flight Programs". The subject NMI provides the following definitions:

1. RISK is exposure to the chance of injury or loss. It It is a function of the possible frequency of the occurrence of an undesired event, of the potential severity of the resulting consequences, and the uncertainties associated with frequency and severity.

2. RISK ASSESSMENT is the process of qualitative risk categorization or quantitative risk estimation, followed by the evaluation of risk significance.

3. RISK MANAGEMENT is the process of balancing risk with cost, schedule, and other programmatic considerations. It consists of risk identification, risk assessment, decision-making on the disposition of risk (acceptance, tolerance through waivers, or mitigation), and tracking the effectiveness of the results of the action resulting from the decision.

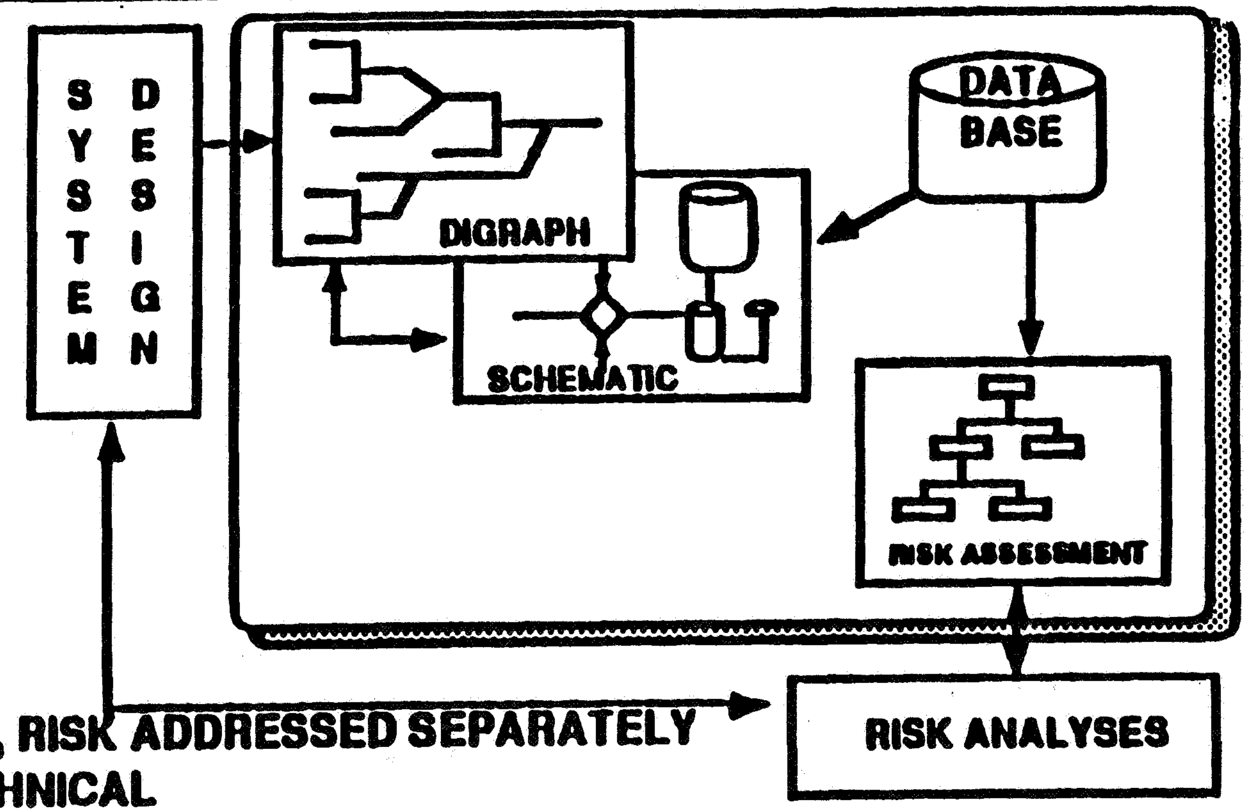
Presently, the practiced forms of risk assessment (Failure Modes and Effects Analyses -FMEA's, Fault Tree Analyses-FTA's and Quantitative Risk Assessments -QRA's) are labor-intensive and unique to the system configuration which was investigated. Basically, they do not lend themselves to easy change following a system modification. It appears that a need exists for a methodology (and associated tools) which allows users to:

1) rapidly define and modify system failure paths for both single and multiple failure sources and targets;

2) provide easy reconfiguration of the system design to understand its behavior in failure space in light of design modifications or, in the case of test or flight operations, its tolerance to the next failure; (Note: Behavior in "failure space" is the logical definition of how systems fail as compared to "success space" wherein functional flow diagrams describe how systems operate.)

FIGURE 1

SYSTEMS RISK ASSESSMENT/ANALYSIS METHODOLOGY:



PRESENTLY, RISK ADDRESSED SEPARATELY
- **TECHNICAL**
- **SAFETY/RELIABILITY**

PRESENT APPROACH PROHIBITIVE
- **SYSTEM COMPLEXITY**
- **EXTENDED EVOLUTIONARY LIFECYCLE**

3) quantitatively define and assess risk for appropriate component, subsystem and system analyses. The programmatic use of the tools associated with this methodology also provides an approach to the capture and maintenance of the system design knowledge. The tools would readily support design and program decisions, test and flight operations; and personnel training.

TECHNOLOGY STATUS

During the post-Challenger investigation, the National Research Council Shuttle Criticality Review and Hazard Analysis Audit Committee expressed concern that the 1,300 safety-critical failure points were not prioritized based on probability of occurrence. They suggested that an integrated systems assessment be devised which would provide for failure probability quantification.

Pilot Studies

During 1987, several studies (sponsored primarily by various Space Shuttle Program and Project Offices) were undertaken to evaluate the usefulness of QRA methodology, and also identify any areas of concern not previously established.

Reference 1 identifies the most significant lessons learned from these studies. The lessons include the positive value of QRA to:

1) provide quantified risk ranking relative to specified top-level events;

2) capture "corporate knowledge" of the system-under-study far beyond their obvious intent;

3) provide a common forum which encouraged inputs from the various Engineering and SR&QA disciplines;

4) provide a convenient tool for management, in that the resulting risk hierarchy aids in the allocation of normally scarce engineering resources.

On the minus side, the magnitude of the project (assessment of Shuttle systems) taxed the existing software tools to their limit. It was clear that new software support is necessary, and full flight systems studies will require expansions of tool capability.

The final lesson focused on the value of system descriptions for the failure space models. These descriptions were found to be necessary in order to define basic failure events. Analysis personnel found the failure-space model definition to be a labor-intensive paper-and-pencil activity. The value of the model was also diminished with modifications to the system-under-study, and the results were limited to unsharable hardcopy.

Tool Prototyping

The National Space Transportation System Program Office sponsored the Shuttle Critical Function Audit (SCFA) Pathfinder Study during 1988 and 1989. Its objectives are to provide organization of the Shuttle Program knowledge base through system diagrams, descriptions and fault tolerance models; the development of a comprehensive risk assessment database; a QRA capability; and the development of a user interface to the model and data.

Directed graph (digraph) modeling is used to provide the medium for analysis of the failure space models. Modeling experience from this program has indicated the need for providing a user-friendly approach to the simultaneous display of conventional system schematics and failure-space models provided by the digraphs.

Digraph Processor

Presently, the standard for digraph model interpretation is the series of Digraph Matrix Analysis programs which were developed by Analytic Information Processing, Inc. The batch-type programs have been found to be satisfactory in the non-realtime failure-space analysis of large complex systems. However, the programs require significant manual effort in analysis of the digraph model's failure reachability information which result from the mainframe processing. Presently, the vendor is developing a faster PC-based version, which will be available for demonstration, but which still requires manual analysis of the results.

Another prototyping effort, under the leadership of the JSC Avionics Systems Division, is the development of a digraph-based failure analysis algorithm. Their Fault Identification and Risk Management (FIRM) program is currently undergoing beta testing.

User Interface

Lockheed Engineering & Sciences Company has developed the Failure Aanalysis Environment Tool (FEAT) which provides the user with a graphics interface to develop the system digraph models, input them to the digraph processor for analysis; then display the results in color either independently or linked to a subsystem schematic. The prototype tool is undergoing beta testing within the company and elements of the Lyndon B. Johnson Space Center (JSC).

The Mission Operations Directorate of JSC has developed the Shuttle Configuration Analysis Program (SCAP), which provides a ground-based diagnostic capability for indicated Space Shuttle system failure symptoms. The tool demonstrates an application which must be supported by emerging risk assessment technology.

Summary

Present software development accomplishments are indicative of the emerging interest in and increasing efforts to provide risk assessment backbone tools in the manned spacecraft engineering community. Reference 2 indicates that similar efforts are underway in the chemical processes industry and are probably being planned for other complex high-risk ground-based environments. However, it appears that complex flight systems intended for extended manned planetary exploration will drive the technology.

TECHNOLOGY ISSUES AND LESSONS LEARNED

1. The protoyping efforts performed to date have indicated promising concepts toward a flexible and maintainable risk assessment methodology. It appears very important to understand and document the various users' needs which will drive the evolving methodology. The existing prototype tools should be used to confirm the methodology through a series of user-oriented demonstrations. The demonstrations will result in constructive criticism which can lead to customer acceptance of the methodology as it evolves. It is absolutely necessary that the various users in the Design, SR&QA, Test and Operations communities become advocates of the methodology in order to meet the intent of NMI 8070.4.

2. The resulting tools must possess satisfactory portability and flexibility to allow rehosting across computer systems with no significant degradation in usability. The goal is to integrate the tools into major program toolsets.

3. The toolset should provide for easy user training, applications development and operations. Although there will be a need for configuration control in the methodology, it should not preclude the user from being able to transport his application (via floppy disks, if necessary) for discussion with members of the community.

4. A process for establishing and maintaining validity of the models must be included in the methodology.

5. The major using Programs must acknowledge and accept the costs of implementing and maintaining the tools.

REFERENCES

1. SPACE SHUTTLE MAIN PROPULSION PRESSURIZATION SYSTEM PROBABILISTIC RISK ASSESSMENT, FINAL REPORT. JSC-22851, February 1988.

2. IEEE TRANSACTIONS ON RELIABILITY, Vol. 37, No.2; June 1988; "On-Line Hazard Aversion and Fault Diagnosis in Chemical Processes: The Digraph + Fault Tree Method"; Ulerich, N. H. and Powers, G. J.

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PRESENTATION 3.4.3

N91-17052

COST ESTIMATION AND BENEFITS ANALYSIS

Space Transportation Avionics Technology Symposium
Systems Engineering And Integration
Cost Estimation And Benefits Analysis
November, 1989

Ed Dean/LaRC
Ernie Fridge/JSC
Joe Hamaker/MSFC

Space Transportation Avionics hardware and software cost has traditionally been estimated in Phase A and B using cost techniques which predict cost as a function of various cost predictive variables such as weight, lines of code, functions to be performed, quantities of test hardware, quantities of flight hardware, design and development heritage, complexity, etc. (Figure 1). The output of such analyses has been life cycle costs, economic benefits and related data. The major objectives of Cost Estimation and Benefits analysis, as an SE&I discipline are twofold: (1) to play a role in the evaluation of potential new space transportation avionics technologies and (2) as a discipline itself, benefit from emerging technological innovations. This paper will discuss both aspects of cost estimation and technology.

First, the role of cost analysis in the evaluation of potential technologies should be one of offering additional quantitative and qualitative information to aid decision-making. Historically life cycle cost analyses, sensitivity studies, risk analysis, and discounted benefits analyses have been utilized to provide comparative economic data to decision-makers on competing technological investment alternatives. Current cost estimating state of the art generally uses parametric estimating approaches in pre-phase A through Phase B for both hardware and software. The design of future launch vehicle avionics will be cost driven. In order to insure that the most cost effective options are identified and accurately compared in total life cycle cost with other options, more accurate cost estimates are needed at all phases of definition.

The cost analyses process needs to be fully integrated into the design process in such a way that cost trades, optimizations and sensitivities are understood. Current hardware cost models tend to primarily use weights, functional specifications, quantities, design heritage and complexity as metrics to predict cost. Software models mostly use functionality, volume of code, heritage and complexity as cost descriptive variables. While these cost metrics have served the aerospace community for over two decades, basic research needs to be initiated to develop metrics more responsive to the trades which are required for future launch vehicle avionics systems. These would include cost estimating

capabilities that are sensitive to technological innovations such as improved materials and fabrication processes, computer aided design and manufacturing, self checkout and many others. Such improvements in the cost estimating process must consider DDT&E, Production and Operations in order to adequately address the total life cycle implications of potential new technologies.

In addition to basic cost estimating improvements, the process must be sensitive to the fact that no cost estimate can be quoted without also quoting a confidence associated with the estimate. In order to achieve this, better cost risk evaluation techniques are needed as well as improved usage of risk data by decision-makers. More and better ways to display and communicate cost and cost risk to management are required.

A real time responsiveness in the cost estimating process is needed. This is hampered in current cost estimating by extensive requirement's placed on the analyst's time for data manipulation. More effective cost models can be instrumental in freeing the cost analysts from much of the low value work involved in estimating and allowing the estimator to concentrate his resources on understanding the technologies being estimated and properly modeling those technologies. While the cost analyst will continue to be a required ingredient, new software techniques approaching and borrowing from expert system technologies may have application to the process. The ultimate in real time response would be a wedding of the CAD/CAM/Cost such that as a designer contemplates a material improvement, a tolerance change or an alternate process, the cost implications could be immediately calculated and displayed.

The technology issues associated with these improvements include the requirements for a better data collection and analysis process so that the real cost driving influences in the historical data base are understood (Figure 2). This would lead to improvement, as already discussed, in the development of more accurate hardware and software cost metrics. Finally, the technology of cost modeling needs user friendly, standardized and more capable applications.

There have been notable accomplishments in aerospace cost estimating. First, a data base based on 30 years of missions has been collected. Many first generation cost models have been developed over the years and successfully used. A few second generation models which are more responsive to technological innovation parameters have been developed. Research is ongoing and needs to be continued to improve this evolutionary process. A host of potential future launch vehicle and non-launch vehicle projects are candidates for the type of improvements in cost estimating discussed here. Each of these projects also requires extensive trades between competing technologies in avionics and in other areas as well. These programs are the leading edge avionics applications now being pursued by both NASA and the DOD and

include Shuttle-C, the Advanced Launch System, the Next Manned Transportation System, Shuttle and Expendable Launch Vehicle improvements, Space Station Freedom, the Lunar/Mars New Initiative and others. By proceeding now to both improve the technology of understanding the economics of these systems and to apply the resulting improved techniques to the systems engineering of these projects, the nation can maximize the return on technological innovation.

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PRESENTATION 3.4.4

N91-17053

SE&I SYSTEM TESTABILITY

SE&I SYSTEM TESTABILITY
THE KEY TO SPACE SYSTEM FDIR AND VERIFICATION TESTING

THOMAS BARRY-NASA/JSC
TERRANCE SCHEFFER-MCDONNELL DOUGLAS SPACE SYSTEMS COMPANY
LYNN R. SMALL-IBM
RICHARD MONIS - HARRIS CORPORATION/GSSD

INTRODUCTION

Space Transportation systems of the future will be required to operate in an autonomous fashion for several years at a time in very remote environments (low earth orbit, on the moon, and other planets). This fact coupled with the fact that maintenance man hours will be severely limited and ground based personnel implementation of test and diagnostics will be too costly for even the most optimistic budget scenario leads us to conclude that on orbit test, checkout and diagnostics must be highly automated and implemented with the same degree of emphasis and importance as functional capabilities.

At the recent space transportation avionics technology symposium, it was pointed out that over 50% of the space shuttle budget is required for operations. All attendees agreed that a primary contributor to this fact was the lack of automation in the test and checkout process and the FDIR system. Future systems must incorporate automated systems, which are well within our present state of the art capability. The Department of Defense has made major strides to eliminate operational costs via the implementation of self-diagnosing systems on all major new aircraft and weapon systems.

The key to implementing self-diagnosing design is a systems engineering task focused on design for testability concurrent with design for functionality.

The design for testability process described herein is the product of several years of DOD study and experience. Its application to the space station has begun on Work Package II under NASA and McDonnell direction. Other work package teams are being briefed by Harris Corporation (with hope) of convincing them to embrace the process.

WHAT IS TESTABILITY

For the purpose of this discussion the term testability is used to describe the systems engineering process by which designers can assure themselves and their reviewers that their designs are "TESTABLE," that is they will support the downstream process of determining their functionality. Due to the complexity and density of present-day state-of-the-art designs, such as pipeline processors and high-speed integrated circuit technology, testability feature design is a critical requirement of the functional design process.

THE OBJECTIVE OF TESTABILITY

In most cases an individual is interested in only one of many uses or reasons for making an item "TESTABLE" or they are involved in only one step in the testability process. However, the needs for testability in a product cover such areas as FDIR, maintainability, safety, design verification, and acceptance testing of the "as-built" product. Each of these uses has special requirements which can be met through providing embedded test points or instrumentation, providing means to open closed loop systems, and using other approaches which increase ones ability to measure the functionality of the product, and to some level of detail, it's component parts. This is usually accomplished with some associated processing software either embedded or in test equipment. The key objectives of the manned space program testability design process are listed in Figure 1.

- Optimize System FDIR
- Optimize System Test and Verification Interfaces
- Minimize Weight and Power of BITE

Figure 1.

THE PROCESS

Figure 2 depicts the flow of system/ORU testability and test procedure development activities which should be integrated into the system/ORU design process.

Maintenance man-hour constraints, astronaut skill level, and other logistics analysis constraints are used to determine on orbit testing requirements. The level of ground participation in operational testing as well as pre-launch test and verification needs are summed up as ground test requirements. With this data the systems engineering process of testability design can begin.

The first step in the process is to allocate testability requirements to BIT vs. on-orbit management systems vs. ground-based work centers. These requirements which involve built in system/ORU interfaces and/or processing for a summary list of testability requirements which must be addressed by system/ORU designers. Items such as fault isolation to one or more ORU's with attendant confidence factor would be a particular element of such a requirements document as would mean time to isolate, etc.

Given these requirements the systems engineering team can concurrently design to the functionality and testability requirements of their system/ORU.

The testability analysis process is one in which the design as defined by a CAE net list or equivalent representation is evaluated manually or computer aided by a system testability analysis software tool to detect design features which threaten the downstream testing process. Such features as closed loop processes, which have no mechanism built in to break the loop, are typical. So the CAE design is iteratively challenged prior to completing detail design to insure testability. A second step in the process involves the generation of a suitable monitoring and diagnostic strategy for the item being designed. This process as was the case in testability analysis can be accomplished in a manual fashion or computer aided using the system testability analysis model. The product of this task is the detail definition of built in test functions such as test points, signal conditioning, and/or data processing which are required to implement the monitoring/diagnostic process. As the system is being designed and developed a parallel activity is conducted by the diagnostics engineer, which will yield test software for both the embedded (on orbit) and off-line (most likely ground based) fault management system. As in the case of testability analysis, this software generation process can be accomplished using computer based software products which will generate machine code to match detail testing procedures for both embedded diagnostics and off-line ATE diagnostics.

At the present time Harris Corporation and McDonnell Douglas are applying computer aided testability analyses to the systems of Work Package II. Figure 2 depicts the process which is being implemented. Using JSC 31000 guidance, testability requirements are being documented in a station level FDIR specification. These requirements are supplemented with RM+S data to form a complete set of station level data. The first task in this process is to develop a dependency model description of the station level connectivity of the Work Package II systems. The testability analysis process is then used to describe a station level diagnostic strategy. The main task of this diagnostic strategy is to do the processing and control functions which are necessary to resolve conflicts between systems. It is that software

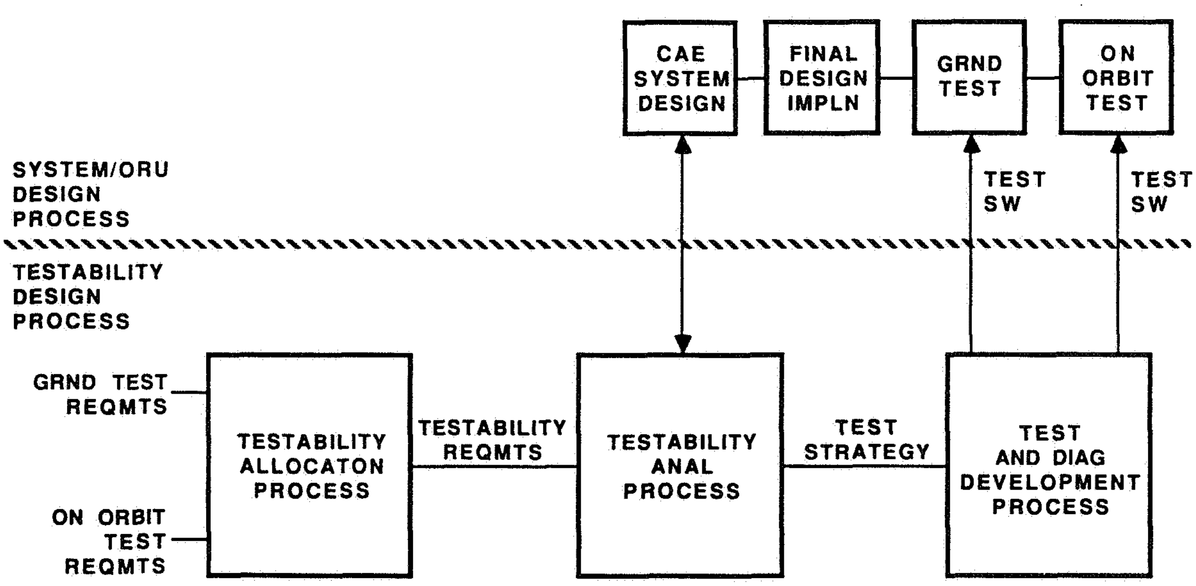

Figure 2. Test and Checkout Development Process

which resolves multiple fault alarms and covers those faults which cannot be handled by the individual systems FDIR software.

Having completed this first step, a specification will be developed which will describe the functions which must be implemented by the OMS system and it will describe for the individual systems design teams (COM + TRACK, GNC, DMS, etc.) the data which they must deliver to OMS to support the station level diagnostics process.

The remainder of Figure 3 shows the activity which will take place within the system level design teams organizations.

The overall impact of this analytically derived top down test strategy development process is an optimization of test point allocation and minimization of data bus traffic, since only data necessary to satisfy the next level of test will be passed from individual built-in test processors. Experience on several large DOD Programs has shown that unless this process is implemented, each system and ORU designer will make a judgment as to what data could be used by the next level diagnostic processor and this leads to computational and data handling explosion.

TESTABILITY TOOLS

Over the past 10 years there have been various pockets of energy within major corporations and small systems engineering houses to develop testability analysis tools. In general all of the tools approach the problem from the perspective of modeling the system/ORU under test using dependency model representation. Once the computer aided design work station has developed this representation, several processor functions are called in to assess testability and interact with the design engineer in a user friendly fashion to help him correct problems noted. Once the system/ORU testability features are included in the design, work begins on the process of selecting optimum search strategies which form the diagnostic (fault tree) approach. Having arrived at this point in the process, an optimum set of test points and test procedures are developed for implementation.

One such testability analysis model has been selected for the Space Station Freedom Work Package II activity. The selected tool is a product of a DOD development contract and as such is available to prime and subcontractor teams. The System Testability Analyzer Tool (STAT) will also be added to the space station Software Support System Environment (SSSE) tool set. Although this tool is being used for the station level work described above by McDonnell/Harris, other subcontractors may be more comfortable with their in-house tool.

The space station testability analysis tool (STAT) is identical to the DOD Weapon System Testability Analyzer (WSTA) tool; this tool is described in detail in Reference I to this paper. Harris Corporation is the developer of this product and may be called for more detailed

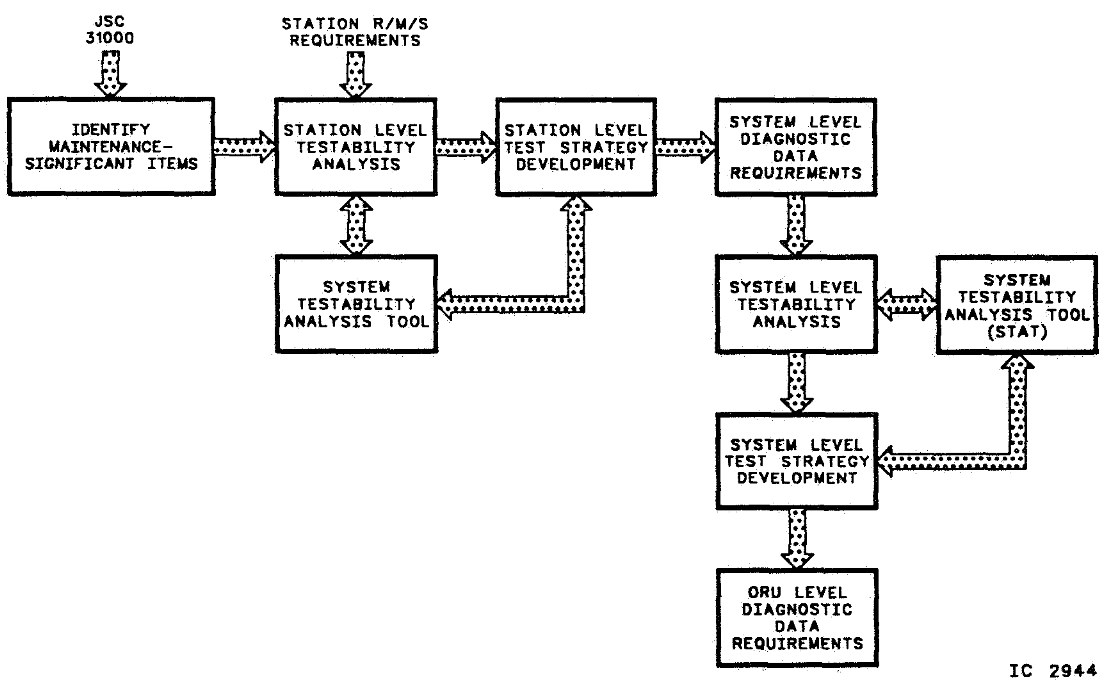

Figure 3. A Top-Down Systems Approach to FD/FI Design

information. The Harris contact is Dr. Bruce Rosenberg and he may be reached at (516) 677-2769. A compatible set of implementation tools are also being developed by the DOD and Harris Corporation which will soon be available to all contractors. The key tool among these is a generic expert diagnostics software package which is designed to be an embedded processor to execute the STAT developed test strategy within a system/ORU or /OMS processor. This tool has data bases which support improvement of testing efficiency over time and a rule based reasoner to accommodate multiple alarms and false alarm discrimination. It is expected that this DOD product will be widely used in both on orbit and ground based testing systems.

IMPLEMENTATION OF TESTABILITY ON SPACE STATION FREEDOM (SSF)

As described above, testability implementation on SSF is a distributed task. The prime contractor MDAC in the case of Work Package II will implement station level testability analysis and test strategy development which will be executed by the OMS. Each of the sub tier contractors (RCA, IBM, Honeywell, etc.) will implement system/ORU testability using software and processors within their systems. Since the SSF STAT will be available to all work package contractors via the SSE tool box, it is expected that they will use it. This tool will be configuration managed by the DOD and Harris Corporation.

TECHNOLOGY ISSUES IN TESTABILITY

Figure 4 lists some of the technology issues being addressed by the SSF contractors and NASA. Although the STAT tool is available today, the system developers are not yet totally aware of it. SSF will be the first real application of testability analysis and development within the space program. It is generally agreed that the process is required to insure maximum operational availability of SSF functions, but this must be communicated across all work packages. To accommodate automatic transfer of CAD data (net lists, etc.) to the STAT tool data base, preprocessors will be required for each CAD system. Two presently exist for Daisy and HP CAD systems.

- TIMELY ACCEPTANCE BY SYSTEM DEVELOPERS
- LACK OF NASA APPLICATION/PROOF OF CONCEPT
- HOW MUCH TESTABILITY IS ENOUGH
- QUANTITATIVE RELATIONSHIP OF TESTABILITY AND AVAILABILITY
- NON-UNIFORMITY OF CAE TO TESTABILITY TOOLS INTERFACES
- TOOL USER FRIENDLINESS

Figure 4. Testability Technology Issues

CONCLUSION

A systematic approach to Space systems test and checkout as well as FDFIR will minimize operational costs and maximize operational efficiency. An effective design for the testability program must be implemented by all contractors to insure meeting this objective. The process is well understood and technology is here to support it.

REFERENCES

Experiences Gained using the Navy's IDSS Weapon System Testability Analyzer

John R. Franco, Jr
Harris Corporation
Government Support Systems Division
6801 Jericho Turnpike
Syosset, New York 11791

An Innovative Approach to Supplying an Environment for the Integration and Test of the Space Station Distributed Avionics Systems

Thomas Barry
NASA/JSC

Terrance Scheffer
McDonnell Douglas Astronautics Company

L.R. Small
IBM

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PRESENTATION 3.4.5

N91-17054

ADVANCED AVIONICS LABORATORIES

Space Transportation Avionics Technology Symposium
Systems Engineering and Integration
Advanced Avionics Laboratories

Introduction

The simulation, development, and verification of advanced avionics systems for launch vehicles have become increasingly complex and expensive tasks. In the past, launch vehicle manufacturers, subsystem vendors, and customers have independently developed specialized laboratories to support their individual needs. This independent development has resulted in duplication of facilities, equipment, software, and labor, and also has resulted in hardware and software incompatibilities between facilities. As our avionics systems move into the 1990's, the laboratory environments in which they are developed must keep pace with technology while also contributing to system cost reductions. A method for accomplishing these seemingly contradictory goals of flexibility and cost reduction is to implement the following Advanced Avionics Laboratory concepts:

- allow support of differing configurations of avionics for one program or multiple programs at a single laboratory facility
- standardize concepts of operation and interfaces used in laboratories of this type so that hardware, software, and results are compatible and may be shared and compared between labs
- provide a suitable proving ground for potentially cost-saving advanced avionics concepts such as Fault Tolerance, Integrated Vehicle Health Monitoring, and Adaptive Guidance, Navigation, and Control

A capsule description of these concepts for Advanced Avionics Laboratories was presented at the NASA Space Transportation Avionics Technology Symposium (STATS) in Williamsburg, VA on November 7-9, 1989. Representatives from each of the major NASA centers and the major aerospace contractors were in attendance, resulting in an unusual opportunity for interchange on current capabilities and needs for the future.

This white paper will describe the presentation on Advanced Avionics Labs at STATS, present the salient points of the ensuing discussion between attendees, and then focus on the necessary areas of concentration in developing the requirements for laboratories which will implement the advanced concepts described above.

STATS Presentation

The STATS presentation on Advanced Avionics Laboratories was produced with the assistance of the subpanel members and presented in a quad chart format (Figures 1 & 2). The subpanel members contributing to the generation of these charts were: Bud Gates and David Hudson of Martin Marietta, Don Johnson of Boeing, Fred Kuenzel of General Dynamics, and Ron White of NASA-Marshall Space Flight Center. The purpose of this presentation was to identify the current state-of-the-art in Avionics Laboratories and the direction that future Laboratory development should take to support the major NASA Space Transportation programs.

The primary objective of Advanced Avionics Laboratory development as identified in the presentation is to provide a "proving ground" for emerging avionics technologies such as: Fault Tolerance; Adaptive Guidance, Navigation, and Control; and Integrated Vehicle Health Monitoring. In meeting this main objective, other important considerations for new laboratories are to reduce development, validation, and verification costs, to encourage resource and data sharing between programs, and to use flexible design and interface techniques to allow for future growth and technology improvements. One method identified for accomplishing these objectives is to implement a "common core" laboratory concept where a central core area with high-cost items may be shared between a number of separate program development activities. Each program would have its own separate development area adjacent to the central core. The equipment identified for the common area might include precision inertial guidance test equipment, optical test and development equipment, and graphic display equipment for real-time presentations to large groups. The program-specific areas would contain items such as software and hardware development workstations, "hot-bench" areas suitable for standalone static subsystem testing, and flexible microprocessor-based interface electronics to connect to the core area for real-time operations. Standard networking tools such as Ethernet, TCP/IP, NFS, X-Windows, etc. would be implemented for non-time-critical data transmission between lab areas.

A number of technology issues were identified as important to the development of these multi-purpose laboratories including:

- trade-offs between real-time, hardware-in-the-loop capabilities and non-real-time, all software simulations
- development of database technologies to allow data sharing across programs

- providing commonality between the modeling/analysis environment and the real-time simulation environment
- defining hardware and software appropriate for common areas vs. program-specific areas
- providing standalone as well as integrated testing capabilities
- providing easy reconfiguration capabilities to support varying hardware and software requirements

Candidate programs identified as potentially benefitting from Advanced Avionics Laboratories were virtually all major NASA programs including ALS (Advanced Launch System), existing Expendable Launch Vehicle Upgrade Programs, Space Shuttle, Shuttle-C, National Aerospace Plane, Advanced Upper Stages such as the Space Transfer Vehicle, Spacecraft programs including the Advanced X-Ray Astronomic Facility, and the Lunar/Mars Initiative.

A number of past, present, and future milestones in Avionics Laboratory development were identified including the AIPS (Advanced Information Processing System) demos at C.S. Draper Laboratory through October 1989, planned MPRAS (Multi-Path Redundant Avionics Suite) demos in 1990-92, and the ALS Vehicle Avionics Simulation Laboratory at NASA/Marshall planned for 1991.

STATS Discussions

Following the Quad Chart presentation, a spirited fifteen-minute discussion ensued in which the major points of the presentation were debated and amplified. A major point was made and re-emphasized that a common laboratory design was needed among the NASA centers and the contractors in order to improve communication, data sharing, and the validity of comparisons between sites. Currently, isolation of effort between the centers is the norm because of a lack of standardization. This isolation results in duplication of effort and wasted time and talents. It was stated that avionics laboratories are needed most during the development and system integration phases and serious operational problems can arise when attempting to use labs for both development and operations such as validation and verification. Concern was expressed that the common core idea is good in theory, but in reality each program manager will want his own lab dedicated entirely to his program. Cultural changes and efficient design will be necessary in order to ease this concern. One point made repeatedly was that the feasibility of the common laboratory design concept is highly dependent on the development of common software interfaces and models, a difficult technical issue. This issue is particularly a problem with regard to

applying standards to programs currently underway such as the Space Shuttle and Space Station. One attendee questioned the value of designing a lab to accommodate future technology advancements if existing technology works and is efficient. The primary thrust of the discussion was that Advanced Avionics Laboratories will be a critical part of the development of avionics for future NASA programs and vehicles and that major changes in the current methods of lab development will be necessary to meet future demands.

Summary of STATS Activity

On the day following the Quad Chart presentations for each subtopic, a summary session was held for the Systems Engineering and Integration subpanel to determine the most useful products of the previous day's discussions. For the Advanced Avionics Laboratories subtopic, it was generally agreed that new, multi-purpose labs providing common hardware and software interfaces will be needed at each NASA avionics center and at each involved contractor. These physically distributed facilities could be connected logically to form a "National Avionics Test Facility" similar to the National Test Bed under development for the Strategic Defense Initiative. Security considerations would be extremely important for such a project but are considered manageable. In order to implement the National Avionics Test Facility, the source of funding would have to be NASA-wide rather than from any one program.

Numerous discussions between participants also took place outside the formal STATS framework regarding Advanced Avionics Laboratories. A number of participants indicated that commonality of operating environments between design, analysis, and lab simulations is highly desirable. Ideally, a flight controls analyst should be able to sit at a workstation, develop a flight control algorithm, run a software simulation against a realistic vehicle model, and then run an actual hardware-in-the-loop simulation for verification without having to change his operating environment for each phase of the process. This type of commonality could greatly reduce time spent and risk incurred due to interchange between groups of analysts, engineers, and programmers all working on different computing platforms and in different environments. Although there is no currently available single operating environment which can encompass all disciplines efficiently, workstation technology is advancing at such a pace that this goal may soon be achievable. The key to implementation of this goal is ensuring that hardware and software interfaces are well-defined and where flight hardware is in the simulation loop the time constraints incurred are not violated.

Although Advanced Avionics Laboratories was a separate subtopic at the Symposium, there were also discussions concerning advanced laboratories during many of the other subtopic presentations. In these other areas the common thread was that advanced laboratory environments are necessary in order to develop and prove advanced avionics concepts. Examples include the Advanced Processors, Advanced Displays and Controls, and Low Cost Avionics subtopics. This widespread recognition of the need for these labs emphasizes the importance of the Advanced Avionics Laboratories concepts previously discussed.

Requirements for Multi-Purpose Laboratories

Cost reduction is the primary factor driving the need for a laboratory supporting multiple avionics development efforts. The high-performance simulation and development environments needed to support state-of-the-art avionics mandate large investments in facilities and high-fidelity test equipment. Development of a "Common Area" housing these high-cost items and sharing these items wherever possible between development efforts can result in tremendous savings.

When considering the concept of a laboratory to be used for multiple development activities, certain trade-offs must be made in order to determine the functions best suited for a common area. One of these trade-offs involves determining when dynamic simulations with flight or breadboard hardware in the loop are appropriate. Certain operations will require hardware-in-the-loop for fidelity during simulations, particularly inertial measurement unit and optical sensor calibration, characterization, and evaluation operations. In order to provide a high-fidelity test environment for these systems, a seismically stable environment must be provided, generally implemented using massive concrete piers isolated from the laboratory structure. To provide a dynamic, flight-like environment for the sensors, a three-axis inertial test table is required. Coordinating table movement profiles with the sensor data in real time during simulations requires a real-time oriented processor with fast input/output capabilities. All of these items are quite expensive and large savings can be realized by providing the proper interfacing to allow multiple programs to use them on a time-sharing basis. Other operations such as standalone subsystem testing and fully software based simulations are more user-specific and require smaller investments in equipment and facilities. These program-specific areas could be located adjacent to the common core and contain flexible microprocessor-based interface electronics to tie them in to the hardware under test in the core. High-cost items necessary

for modeling, characterization, and hardware-in-the-loop simulation of avionics components include:

- Seismically quiet environments for IMU evaluation and testing
- Three-axis inertial test tables and indexing heads for IMU evaluation and testing
- Real-time hardware-in-the-loop oriented simulation host computers
- Graphic display systems to aid data interpretation
- Optical testing environments for star trackers, star scanners, etc.
- Analysis equipment including spectrum analyzers, signal analyzers, etc.

Each of these items could be candidates for location in a central core area accessible on a time-sharing basis to multiple development efforts. The use of a common core labor force able to support hardware-in-the-loop simulations for multiple programs can also result in large labor savings. To date, the tasks of configuring a simulation system for real-time runs, managing databases, operating the system, and acquiring and reducing data have required large staffs, duplicated for each laboratory. Advances in technology will allow reductions in the size of this labor force, and a common area implementation will allow sharing of the labor cost between programs. An example of a laboratory configuration which could support multiple development efforts is shown in Figure 3.

Benefits From Commonality

Another factor supporting the development of multi-purpose laboratories is the potential benefit from sharing data between related avionics development efforts. Typically, avionics laboratories produce tremendous quantities of raw data from simulation, and use a large number of personnel to reduce that data and draw results. Providing the data and results in a form usable by multiple development activities can also result in less duplicated effort. The key component necessary to allow this data sharing activity is commonality of software models, databases, and operating environments. In addition, common data transfer formats and media between facilities must be provided to permit timely data transfers between geographically separated laboratories.

The real-time control and simulation requirements for particular programs and particular disciplines within programs may vary greatly with regard to the hardware interfaces to flight-type equipment. For example, a simulation laboratory for an advanced expendable launch vehicle may require relatively slow loop rates in the 10-100 Hz range for vehicle guidance and control functions, but may require rates of 100-1000 Hz for high-

speed engine control and monitor functions. A flexible, expandable real-time interfacing architecture is a must for an advanced, multi-purpose avionics laboratory. The real-time operating environment should be standardized across geographically separate laboratories to maximize the validity of data sharing and comparisons between sites.

Flexibility and Expandability

In order to provide maximum flexibility and minimize costs due to interface incompatibilities, standard hardware and software should be used wherever possible. Examples of current standards which may be applicable to the Advanced Avionics Laboratory architecture include FDDI, Ethernet, NFS, and TCPIP for networking, X-Windows and PHIGS for graphics software, UNIX for workstation operating systems, Ada for software development, VMEBus, Multibus, and Futurebus for microcomputer backplanes, and the Mil-Std-1553B avionics bus.

The hardware and software architecture must be modularized to the greatest extent possible to provide expandability and adaptation to future changes in requirements. The central host computer, graphics workstations, and interface electronics must all have a modular design in order to accommodate anticipated changes in requirements for the number and types of processors, number and types of hardware interfaces, Input/Output bandwidth and communications bandwidth. To provide true flexibility of operations, each program's facility and the subsystems within must be able to operate independently of the others. To meet this goal, each facility must contain a certain amount of development capability as well as the operational interfaces to connect it to the Common Core Area. The software architecture for the labs must also be modularized with the goal of providing rapid prototyping capabilities. Easy transitions from software simulations to simulations with various configurations of flight-type hardware will greatly enhance the efficiency and productivity of the laboratory.

Special Considerations

Certain special considerations are necessary when defining the electronics for a real-time simulation facility which will contain hardware in the control loops and will be used to support multiple development efforts. These special considerations have a great deal of impact on the overall system architecture, particularly with regard to inter-computer communications and connections from computer-based controllers to simulated flight hardware, breadboards or actual flight articles.

Software-Based Simulations

Full software simulations of complex electromechanical control systems are possible using the quickly evolving high speed families of desktop workstations. These stations can perform extremely high definition simulations and have become the workhorses for Computer Assisted Design/Computer Assisted Engineering (CAD/CAE) applications. The operating system of choice on most high performance workstations is UNIX, providing a high degree of portability for applications. UNIX is flexible, powerful, and capable of handling the most difficult simulation problems. The drawback to using a UNIX-based engine for simulation is its inability to operate in real-time and control actual hardware. This however is generally not a problem during the initial system, component, and algorithm development stages. High definition graphics output, coupled with the workstations' power to solve complex math-intensive problems, allows the control systems designer to see the results of changing control algorithms, plant dynamics, and other control critical parameters without having to deal with cumbersome pieces of hardware and test equipment.

Hardware-In-The-Loop

When simulations are performed completely in software without hardware stimulation and response, synchronization of the various parts of the simulation is not a time-critical concern and the phase relationship between various operations may be controlled with relative ease. The introduction of hardware into a control system simulator brings with it a whole new family of problems. Hardware-in-the-loop simulations are generally time and phase critical and must be closely synchronized to the digital control processors used to close the loops. Deterministic control algorithms must be designed to insure that timing errors such as control frame overruns can not occur. The hardware must be designed to minimize latency of responses to external events and to insure that no undefined timing jitter will be added by the interfaces. Any timing uncertainties induced by algorithms or hardware will result in undesirable phase errors and time aliasing creeping into the control loops. These types of errors will result in the inability to time correlate multiple control loops and will cause unreliable test results and output data.

Embedded Controllers

The design of true real-time control system hardware requires the design of dedicated interface electronics with embedded microprocessor controllers. These dedicated interfaces provide the wide I/O bandwidths and high-speed mathematics necessary to close robust precision servo loops. Hardware-In-The-Loop Simulations require very high bandwidth local control loops to ensure sufficient phase margins for an unconditionally stable system. These types of local loops generally require embedded controllers running at control loop frequencies 10 to 100 times faster than the host computer loop frequencies. The embedded controllers are typically responsible for the mathematics required to compensate local control loops, such as State Variable Control and Proportional, Integrator, Differentiator (PID) types of compensators. Wide bandwidth dedicated buses are used to ensure that data is always available to the processors and to the actuators at the same time in each frame. This guarantees that there will be no timing inconsistencies to cause loop overrun errors or time aliasing. Fast interprocessor communications are required for concurrent algorithm processing. Intermediate control variables to be passed from controller to controller or to the data logger interface are passed on this type of interface.

Analog Interfaces

In order to provide extremely accurate and reliable control of sensor and actuator interfaces, precise and noise-free analog interfaces must be implemented. To provide the maximum noise immunity for analog signals, a low impedance balanced differential signal path must be used and the physical distance between drivers and receivers must be minimized. When these guidelines are followed, accuracies of up to 15 bits during D/A and A/D conversions may be attained. This level of accuracy will allow precise control of actuators and minimize jitter due to quantization noise. The sampling and command rates for all servo hardware must be completely synchronous and phase-locked. A flexible scheme of distributing a hardware synchronization pulse to the remote analog and digital data acquisition electronics and the controlling computer systems must be implemented. The hardware synchronization system should be capable of providing phase-locked synchronization pulses throughout the system at frequencies varying from 10 Hz to 10 KHz. Where possible, sensors should be sampled at a rate ten times the command frequency in order to maximize the phase margin for each control loop. Anti-aliasing filters must be implemented for each sensor input and data smoothing filters for each actuator

output to eliminate aliasing errors and undesired high-frequency signal components. Power for the hardware under test should be isolated as much as possible from the electrically noisy computer environment in order to provide maximum noise immunity. This may be accomplished by means of fiber optic data links and opto-isolators at critical interfaces. As stated above, distribution of analog signals should be by means of differential amplifiers and receivers wherever possible.

Host Computer

Typically, a real-time simulation laboratory will require the use of a modern high speed, multiple processor, concurrent algorithm computer. This computer will handle the high level mathematics, simulation control, and man-machine interfaces for the entire laboratory complex. The real-time frame rate for the host machine will generally be from 10 to 100 times slower than the rate for the the local control processors. The host will be required to handle most of the mathematics associated with the equations of motion and will be required to solve math intensive problems including rigid and flexible body mechanics. The host computer must be capable of very wide I/O and interprocessor backplane bandwidths. Data must be passed to and from local control processors quickly in order to avoid an adverse impact on the processing time available to the local controllers. Data and intermediate control variables must also be passed between CPUs inside of the host computer system to allow for interaction between concurrently operating servos and algorithms.

Summary

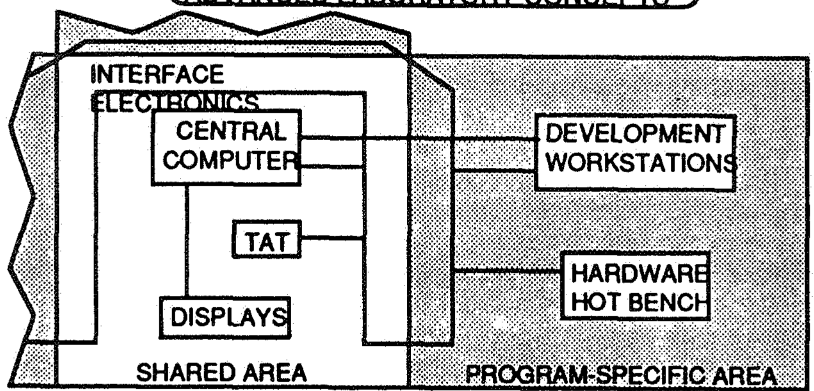
In order to develop the new generation of avionics which will be necessary for upcoming programs such as the Lunar/Mars Initiative, Advanced Launch System, and the National Aerospace Plane, new Advanced Avionics Laboratories are required. To minimize costs and maximize benefits, these laboratories should be capable of supporting multiple avionics development efforts at a single location, and should be of a common design to support and encourage data sharing. Recent technological advances provide the capability of letting the designer or analyst perform simulations and testing in an environment similar to his engineering environment and these features should be incorporated into the new laboratories. Existing and emerging hardware and software standards must be incorporated wherever possible to provide additional cost savings and compatibility. Special care must be taken to design the laboratories such that real-time

hardware-in-the-loop performance is not sacrificed in the pursuit of these goals. A special program-independent funding source should be identified for the development of Advanced Avionics Laboratories as resources supporting a wide range of upcoming NASA programs.

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
SYSTEMS ENGINEERING AND INTEGRATION
ADVANCED AVIONICS LABORATORIES
FIGURE 1

NOVEMBER 1989

ADVANCED LABORATORY CONCEPTS



SHARED AREA	PROGRAM-SPECIFIC AREA
- IMU Cal, test, and eval - HWIL Simulation - Data acquisition, logging, and display	- Software development - Subsystem development and simulation - "Hot Bench"

MAJOR OBJECTIVES

- Provide a proving ground for advanced avionics concepts (Fault Tolerance, AGN&C, advanced sensors, integrated VHM)
- Reduce development and V&V costs via:
  - common hardware and facilities
  - commonality of software models and database structures
  - reduced manpower requirements for operational support
  - more efficient operations
- Provide a common development environment to encourage data sharing between programs
- Provide growth path for adaptation to new technologies

KEY CONTACTS AND FACILITIES

<u>Contacts</u>
Chuck Meissner, Felix Pitts/LaRC
Ken Cox/JSC
Ray Bortner/WRDC
Whit Brantley, Ron White/MSFC
Don Johnson/Boeing
Fred Kuenzel/GD
Crane Simmons/MDAC
Bud Gates/MMAG
Leon Shockley/RIC
Jay Lala/CSDL

<u>Government Facilities</u>
AIRLAB - LaRC
WRDC labs
MSFC labs - APC, SSME lab
JSC labs - SAIL

<u>Contractor Facilities</u>
ELV Labs at MMAG, GD, MDAC
Shuttle labs at RIC
Boeing System Integration Labs
CSDL Labs

MAJOR MILESTONES

- AIPS demos at CSDL - Oct 89
- MPRAS Demos
  - Key Concepts Mar 90
  - Subsystems Jul 91
  - Full Architecture May 92
- Shuttle-C Avionics Lab (MSFC)
  - S/W only capability Aug 90
- ALS Vehicle Avionics Simulation Laboratory (MSFC)
  - IOC Oct 91
  - Operational Aug 93

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
SYSTEMS ENGINEERING AND INTEGRATION
ADVANCED AVIONICS LABORATORIES
FIGURE 2

NOVEMBER 1989

TECHNOLOGY ISSUES

- Cultural changes necessary for acceptance of advanced avionics concepts
- Real-time hardware-in-the-loop simulation vs. all software approach
- Common database technology for multiple programs
- Providing easy transition from modeling/analysis environment to HWIL simulations
- Defining hardware and software appropriate for common areas
- Providing standalone as well as integrated testing
- Ease of reconfigurability

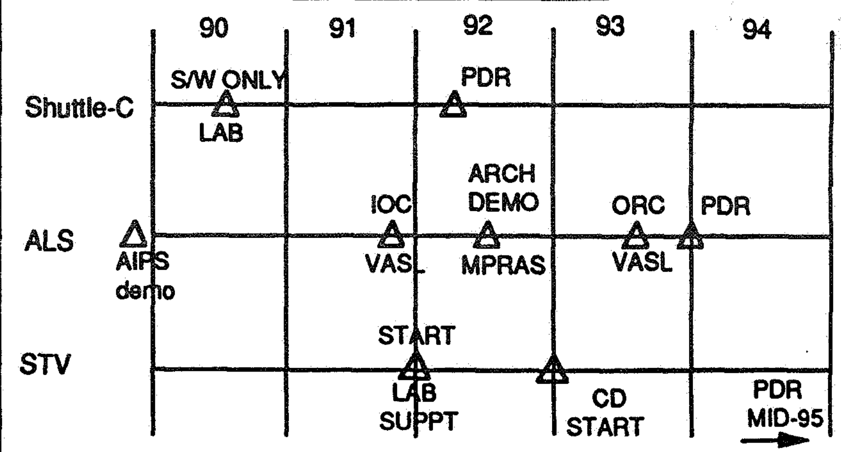
CANDIDATE PROGRAMS

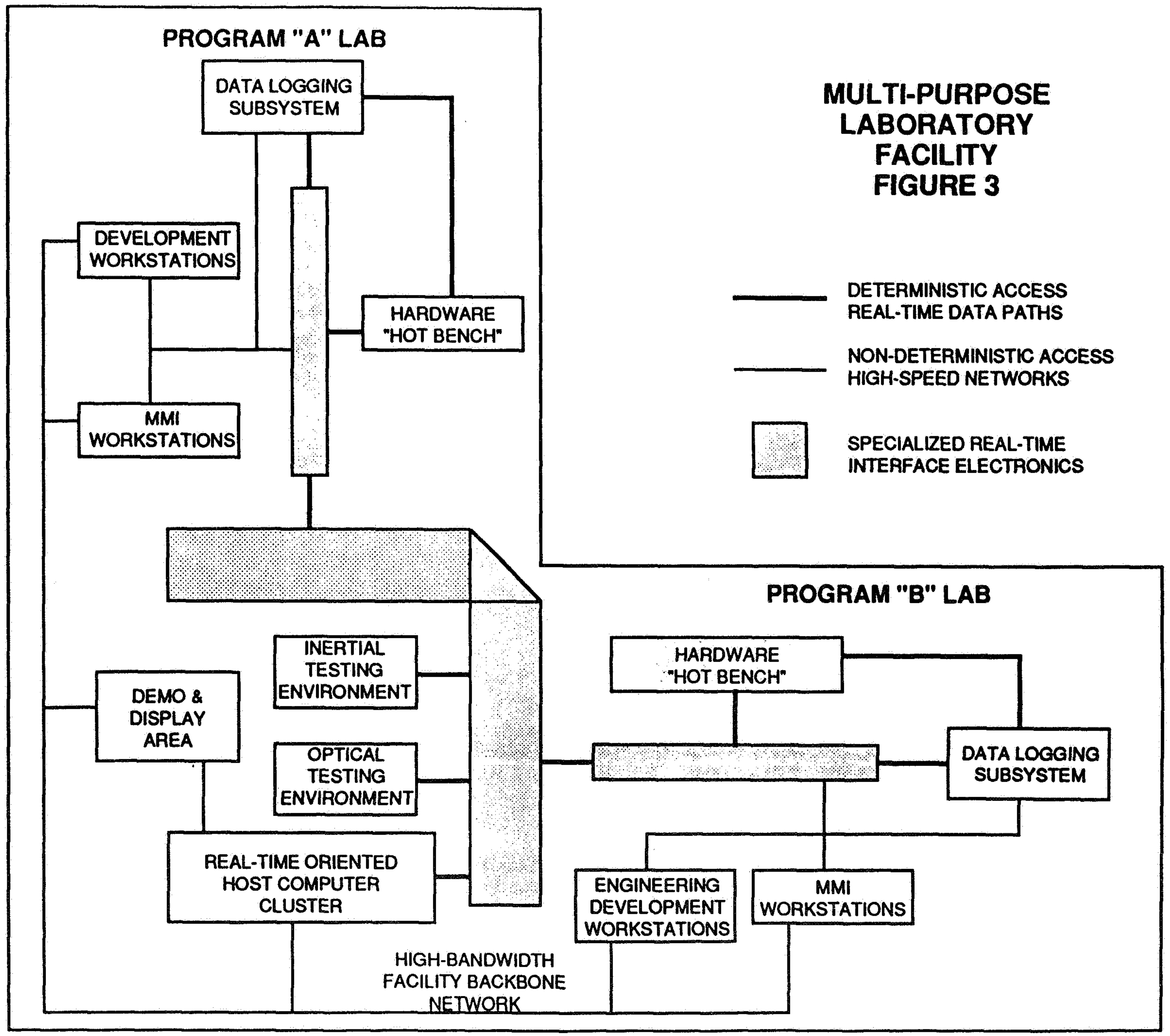
- ALS
- ELV Upgrade Programs
- Shuttle
- Shuttle-C
- NASP
- Advanced upper stages (STV)
- Spacecraft programs (AXAF, others)
- Lunar/Mars Vehicles

MAJOR ACCOMPLISHMENTS

- Test, Evaluation, Integration, and Test Facility at CSDL - Oct 89
  - Supports LaRC-sponsored AIPS Distributed System
- HLCV/MAST Laboratory
  - Preliminary designs completed Feb 89
  - Concept demonstrations performed May-Sep 89

SIGNIFICANT MILESTONES





MULTI-PURPOSE LABORATORY FACILITY
FIGURE 3

PANEL REPORTS

- OPERATIONAL EFFICIENCY
- FLIGHT ELEMENTS
- PAYLOAD ACCOMMODATIONS
- SYSTEMS ENGINEERING AND INTEGRATION (SE&I)

PANEL REPORTS

742

5307I4
34P

PRESENTATION 4.1

N91-17055

OPERATIONAL EFFICIENCY

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM

OPERATIONAL EFFICIENCY

PANEL FINDINGS

DAN BLAND (JSC)
TOM DAVIS (KSC)
SANDY GRIFFIN (HQ-MD)

NOVEMBER 9, 1989

STATS - OPERATIONAL EFFICIENCY

Introduction

- **OPERATIONAL EFFICIENCY COVERS ALL TECHNOLOGY DISCIPLINES AND PROGRAMS**
  - There Is, However, More To Operating Efficiently Than Judicious Use Of Technology (e.g. Appropriate Organization Structure, Clean Interfaces Between Disciplines, Etc.)
  - Separate Efforts Are Underway To Address These Issues (e.g. JSC Mission Operations Efficiency Study, KSC Launch Operations Efficiency Study)
- **CROSS PANEL TECHNOLOGY NEEDS SHOULD BE INTEGRATED**
- **STATS PROVIDED BROAD MIX OF PROGRAM TECHNOLOGY NEEDS, TECHNICAL DISCIPLINE NEEDS, TECHNOLOGY AVAILABILITY**
  - Specific Technology Needs Must Be Defined And Prioritized Against TBD Meta- Program Requirements
  - Technology Needs vs Technology Availability Analysis Can Then Be Performed To Define Holes

STATS - OPERATIONAL EFFICIENCY

Ascent Flight Design *

- **KEY FINDINGS**

  - An Opportunity Exists For Progressively Automating And Standardizing The Ascent Flight Design Process Through The Use Of Advanced Technologies
  - Over Time, The Ascent Flight Design Process Will Evolve From Ground-based Technologies To Launch Vehicle-based Technologies
  - Launch Vehicle On-board Ascent Flight Design Capability Will Significantly Reduce Pre-launch Support Requirements And Improve Launch Probability
  - There Is Currently No Integrated Code M / Code R Plan For Exploiting This Opportunity

* COVERS BOTH <u>AUTOMATIC FLIGHT DESIGN</u> AND <u>ATMOSPHERIC ADAPTIVE GUIDANCE</u> TOPICS

STATS - OPERATIONAL EFFICIENCY

Ascent Flight Design *

- TECHNOLOGY NEEDS

  - Full Integration / Automation Of Distributed Ground Processes
  - On-board Computational Capabilities
  - On-board Upper Wind Measurement Systems (e.g. LIDAR)
  - Large Data Base Systems
  - Better Atmospheric Modeling
  - On-board Parallel Processing Hardware & Software
  - Advanced Sensors: Winds, Air Loads, Etc.

* COVERS BOTH AUTOMATIC FLIGHT DESIGN AND ATMOSPHERIC ADAPTIVE GUIDANCE TOPICS

STATS - OPERATIONAL EFFICIENCY

Ascent Flight Design *

- **CULTURAL CHANGES**

  - Use Standard Trajectory Designs Rather Than Optimum Designs (Flight Vehicle & Simulators)
  - Synergize Effort With DoD ELV Flight Design Systems
  - Stop Late Changes To Vehicle Constraints
  - Crew / Ground Controller Acceptance Of Standard I-loads

- **FACILITIES**

  - No New Facilities Required

*** COVERS BOTH AUTOMATIC FLIGHT DESIGN AND ATMOSPHERIC ADAPTIVE GUIDANCE TOPICS**

STATS - OPERATIONAL EFFICIENCY

Autonomous Spacecraft Control

- **KEY FINDINGS**
  - Needs Of This Program Seem To Duplicate DARPA "Pilots Associates Program" - Integration Needed
  - Very Broad Area - Covers Many Technologies And Programs
  - Will Become Increasingly Important As Requirements For Automated Rendezvous And Docking, Remote Descent / Ascent, And Autonomous Surface Operations Increase

- **TECHNOLOGY NEEDS**
  - On-board Task Planning & Management Systems
  - Intelligent GN&C Systems
  - Advanced Sensors
  - Intelligent Effectors
  - Standardized Spacecraft-to-Spacecraft Interfaces

STATS - OPERATIONAL EFFICIENCY
Autonomous Spacecraft Control

- **CULTURAL CHANGES**
  - Center & Organizational Responsibility Overlap Causes Duplication Of Efforts - Ineffective Use Of Resources
  - Will NASA Accept Autonomous Operation Of Manned Spacecraft Or With Unmanned Spacecraft Docking With Manned Spacecraft?
  - NASA Needs To Assure Cross Utilization Of Control System Hardware & Software Between Programs

- **FACILITIES**
  - Not Addressed

STATS - OPERATIONAL EFFICIENCY
Operations Management Systems

- **KEY FINDINGS**
  - OMS Is A Major Need Across All Programs And Becomes Mandatory With Program Complexity - e.g. SSF
  - Ground And On-board, Manned And Unmanned Applications
  - NASA Needs Cross-program Coordinated Effort For This Complex Discipline (M, S, R, E)

- **TECHNOLOGY NEEDS**
  - Artificial Intelligence
  - Advanced Computer & Software Architectures
  - Software Commonality (Retrofit Current Programs, Drive Future Programs)
  - Advanced Man-Machine Command & Control Interfaces

STATS - OPERATIONAL EFFICIENCY

Operations Management Systems

- **CULTURAL CHANGES**
  - This Must Not Be Assumed To Be An Easy Task
    - *Distributed Development Of An OMS For A Complex Spacecraft Will Introduce Significant Program Risk*
  - Crew Members Want To Know (And Have The Capability To Control) <u>Everything</u> About Their Vehicle

- **FACILITIES**
  - Integrated Test Bed At JSC

STATS - OPERATIONAL EFFICIENCY

Advanced Mission Control

- **KEY FINDINGS**
  - Earth-based Ground Support To Space-based Operations (Orbital Operations, Planetary Surface) <u>Must</u> Be Automated To A High Degree To Reduce Resources Needed For Continuous Long Term Programs (e.g. SSF, Lunar, Mars)
  - The "Capture" And Utilization Of Systems Data From Current And Past Programs Is A Vital Aspect Of This Technology
  - Technologies So Developed May Be "Transported" To Orbital And Remote Surface "Control Centers"

- **TECHNOLOGY NEEDS**
  - Large Scale Knowledge & Data Bases
  - Automated Knowledge Acquisition, Storage, Utilization
  - Qualitative / First Principles Reasoning
  - Autonomous Trend Analysis
  - Ability To Accept And / Or Express Processed Data In The "Language" Of The User

STATS - OPERATIONAL EFFICIENCY

Advanced Mission Control

- **CULTURAL CHANGES**
  - Joint Funding Of Research And Advanced Development As Technology Matures
  - The Need To Transition From Old (But Proven) Flight Control Technologies And Methods To New (And As Yet Unproven) Technologies And Methods Is Often Difficult To Sell

- **FACILITIES**
  - ARC AI Research Laboratory

STATS - OPERATIONAL EFFICIENCY

Telerobotics / Telepresence

- **KEY FINDINGS**
  - Development Work At JPL, ARC, And LaRC Not Adequately Covered; Program Needs Better Cross Center / Program Integration
  - Integration Of Inter-center A&R Research Is Vital
  - Telerobotic Research Has Not Adequately Been Bridged Into Mainstream Applications
  - A&R Will Be <u>Enabling</u> To Programs Such As SSF, ACRV, OMV, Lunar / Mars Exploration

- **TECHNOLOGY NEEDS**
  - Advanced Manipulators
  - Global / World Data Base
  - Fault Tolerant Systems
  - Sensors
  - Display Technologies
  - Collision Avoidance
  - Human Factors

STATS - OPERATIONAL EFFICIENCY

Telerobotics / Telepresence

- **CULTURAL CHANGES**
  - Telerobotics Technologies Not Well Accepted Throughout NASA (e.g. FTS)
  - Centralization Of Telerobotics / Telepresence R&D Effort Could Save Agency $$$ (Currently, Every NASA Center Has A&R Research Labs)

- **FACILITIES**
  - No New Facility Requirements Identified

STATS - OPERATIONAL EFFICIENCY

Advanced Software Integration

- **KEY FINDINGS**
  - Complex / Long Term Programs (e.g. SSF, Lunar, Mars) Will Require Major Advancements & Commitments To Advanced Software Integration Technologies And Capabilities
  - The More Distributed The Development Of Application Software Packages, The Greater The Need For A Centralized Software Integration, Testing, And Verification Capability Prior To "Flight"

- **TECHNOLOGY NEEDS**
  - Distributed Software Security
  - Modeling Of Complex Distirbuted Software Systems
  - Software Standards Development
  - Virtual Target Environments

STATS - OPERATIONAL EFFICIENCY

Advanced Software Integration

- **CULTURAL CHANGES**
  - Design / Operational Problems Involving Long Term Missions & Complex Software Integration Requirements Are Often Underestimated
  - Future Integration Of SSF And STS Software Development And Maintenance Concepts / Facilities Will Be Required For Economic (And Practical) Reasons

- **FACILITIES**
  - Integrated Test & Verification Facility At JSC (Multi-program Support)

STATS - OPERATIONAL EFFICIENCY

Advanced Test / Checkout Systems

- **KEY FINDINGS**
  - NASA Needs To Make An In-depth Analysis Of Aircraft Industry (Commercial & Military) Test & Checkout Methods
  - Launch Vehicle And Payload On-board Test Capability Should Greatly Reduce Ground Support Requirements

- **TECHNOLOGY NEEDS**
  - Better Life Cycle Cost Analysis Tools / Methods
  - Artificial Intelligence
  - Data Storage Devices
  - Distributed Computer / Software Systems

STATS - OPERATIONAL EFFICIENCY

Advanced Test / Checkout Systems

- **CULTURAL CHANGES**
  - Program Commitment To Launch Vehicle And Payload On-board Test And Checkout
  - Syndrome Requiring Test And Re-test Of Systems
  - Inabililty To Accept Autonomous Operations

- **FACILITIES**
  - Need A Test Facility Where High Fidelity Transportation Systems And Payload Systems On-board Autonomy Can Be Demonstrated

STATS - OPERATIONAL EFFICIENCY

Health Status and Monitoring

- **KEY FINDINGS**
  - Health Status Covers End-to-End Process: Component Manufacturing, Testing, Pre-flight, Flight, And Post-flight Elements
  - Health Status And Monitoring Capabilities Must Be Incorporated Early In DDT&E
  - Important To Define Key Parameters To Be Monitored Within Each Process Element, To Define Inter-element Parameter Dependencies, And To Integrate And Status Realtime Parametric Data

- **TECHNOLOGY NEEDS**
  - Design Knowledge Capture, Utilization And Maintenance
  - Embedded Sensors (Smart)
  - Large Data Bases (Integrated Data / Knowledge)
  - Distributed Computer & Software Architectures (Highly Reliable)
  - High Speed Data Analysis (Pattern Matching)
  - Techniques For Inferred Monitoring

STATS - OPERATIONAL EFFICIENCY

Health Status and Monitoring

- **CULTURAL CHANGES**
  - NASA Doesn't Consider HS&M To Be A High Priority - Requirements Deleted Under Budget Crunches
  - Incidents Such As The Recent DC-10 Fan Disk Failure Illustrate The Importance Of This Technology To Mission Success And Crew Safety

- **FACILITIES**
  - Not Addressed

STATS - OPERATIONAL EFFICIENCY

Advanced Training Systems

- **KEY FINDINGS**
  - As NASA Moves To More Autonomous Operations, Intelligent Computer-Aided Training (ICAT) Will Be Required To Assure Operational Efficiency Maintenance
  - Specific Applications Are Ready For Placement Into Current NSTS Program Operations

- **TECHNOLOGY NEEDS**
  - Knowledge Acquisition Tools
  - Advanced Computer Architectures
  - Advanced Simulation Techniques
  - Virtual Systems

STATS - OPERATIONAL EFFICIENCY
Advanced Training Systems

- **CULTURAL CHANGES**
  - Management Acceptance Of ICAT Technologies Is Good

- **FACILITIES**
  - Not Addressed

STATS - OPERATIONAL EFFICIENCY

Bottom Line

Operational Efficiency Is Not A Major Technical Problem.

It Is A Cultural (Political / Funding) Problem!

743

530715
28P

PRESENTATION 4.2

N91-17056

FLIGHT ELEMENTS

SPACE TRANSPORTATION AVIONICS

TECHNOLOGY SYMPOSIUM

FLIGHT ELEMENTS SUBPANEL

SUMMARY OF FINDINGS

CLAUDE R. KECKLER

NOVEMBER 9,1989

FLIGHT ELEMENTS

- ADVANCED AVIONICS ARCHITECTURE
- ADVANCED PROCESSORS
- INTEGRATED GPS/GN&C
- ADVANCED DISPLAYS & CONTROLS
- ADVANCED COMMUNICATION & TELEMETRY

- ADVANCED SENSORS & INSTRUMENTATION
- FAULT DETECTION & FAULT MANAGEMENT
- ADVANCED ELECTRICAL POWER DIST. & CONTROL
- EMA/POWER SYSTEMS
- INFLIGHT CREW TRAINING

MISSIONS

NEEDS	STS	HLLV	TV	LMI
AAS	√	√		
LOWER OPS COST		√	√	√
LIFE/RELIABILITY		√	√	√
AUTONOMY		√	√	√
S/W	√	√	√	√

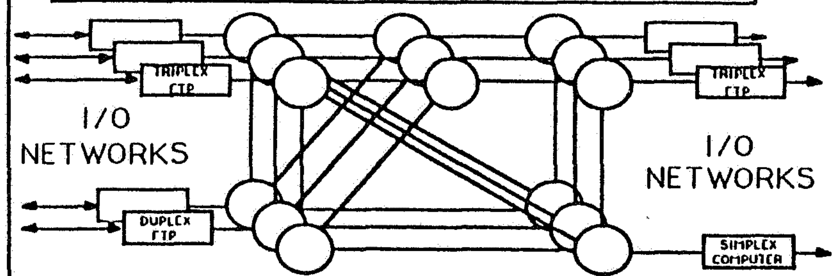
SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM

FLIGHT ELEMENTS

ADVANCED AVIONICS SYSTEMS ARCHITECTURES

NOVEMBER 1989

Advanced Information Processing System



Features:
- ADA Operating System
- Fault-Tolerant Distributed Processing Sites
- Fault-Tolerant Inter-computer Network
- Appropriate Function Reliability
- Low Fault Tolerance Overhead
- Growth Capability
- Redundancy Transparent to User

Major Goals and Objectives:

- Improved Reliability at Lower Cost
- Low Recurring Hardware and Operations Cost
- Enable/Support Launch-On-Demand
- Open-Ended Architectures that Support System Growth and Change
- Vehicle-Wide Standardization of Architectural Concepts
- Autonomous, Factory-To-Flight Subsystem Integrity and Confirmation
- Enable/Support Autonomous Long Duration/Distance Flight Operations
- Flexible/Secure Interfaces for Payload and Other Non-Avionic System Support
- Autonomous Pre-Flight System Support and Test

Key Contacts:

JSC- Tom Barry, Tom Morre	BAC - D. Johnson
LaRC - C. Meissner, F. Pitts	CSDL - J. Lala
LeRC - H. Wimmer	GD - J. Karas
MSFC - W. Chubb, W. Brantley	HI - J. Weyrauch
WDRC - J. Stanley, R. Bortner	RIC - L. Shockley
JPL - D. Rennels	MMC - R. Gates

Facilities

- -JSC Avionics Eng. Lab
- -MSFC Avionics Productivity Center
- -LaRC AIRLAB

Major Milestones (1990-1995):

TECHNOLOGY DEMO'S IN WORK:

- MPRAS
- Common Module Military Aircraft Flight Tests

RECOMMENDED DEMOS:

- Define System Goals and P31 Planning (90 and 91)
- Joint Lab Demo's at MSFC/JSC with FLT Test at Ames (92 and 93)
- Insertion on Combined STS and Shuttle-C Upgrades

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM

FLIGHT ELEMENTS

ADVANCED AVIONICS SYSTEMS ARCHITECTURES

NOVEMBER 1989

Technology Issues:

- Level of Fault Tolerance
- Cost vs. Reliability
- *Utility of Building-Block Architectures*
- Modeling/Test Mix for Validation
- Design for Launch-With-Failures
- EME-HARD Design and Assessment
- *Software Development Environment*
- ADA *Software for High-Bandwidth Control*

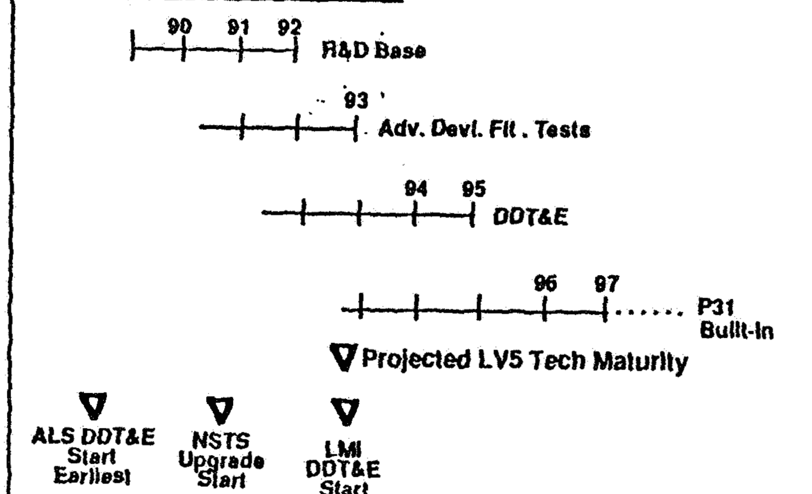
Candidate Programs:

- Assured Shuttle Availability, Unmanned Orbiter
- NASP, CERV
- Shuttle-C, ALS
- Existing Launch Vehicles
- SSP, Lunar Mars Initiative

Major Accomplishments:

- Space Station Avionics Design Captures Some Objectives
- ALS Requirements and Advanced Technology Development Meets/Exceeds Objectives
- Advanced Military Aircraft in DDT&E (A-12 and ATF) Captures Objectives and Developing Usable Hardware
- Commercial aircraft fault-tolerant / distributed systems

Significant Milestones:

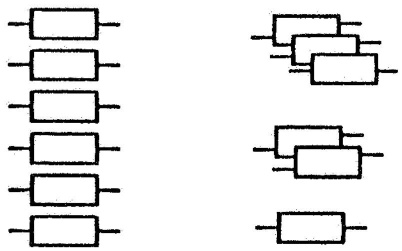


SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
FLIGHT ELEMENTS
ADVANCED AVIONICS ARCHITECTURE

NOVEMBER 1989

ADVANCED AVIONICS CONCEPTS

EXPLOIT THE POTENTIAL SYNERGISM BETWEEN PARALLEL PROCESSING AND REDUNDANCY



MAJOR OBJECTIVES:

PROVIDE THE SYSTEM ARCHITECTURE TO ACHIEVE

- HIGH PERFORMANCE (.1 TO 10 GOPS)
- RELIABILITY FOR EXTENDED MISSIONS (1,000 - 10,000 HRS)
- AUTONOMY TO ADAPT TO CHANGING SITUATIONS AND MISSION MODES
- SEAMLESS HARDWARE AND SOFTWARE TRANSITIONS BETWEEN EPOCHS
- BUILT IN -
  - ON-LINE MODULE LEVEL VALIDATION
  - OFF-LINE COMPONENT LEVEL SELF TESTABILITY
- LOW POWER , WEIGHT, AND VOLUME
- RADIATION HARDNESS

KEY CONTACTS:

- H. BENZ (LaRC)
- J. DEYST (CSDL)
- T. DE YOUNG (DARPA)
- B. J. THOMAS (IBM)

MAJOR MILESTONES (1990-1995):

CONCEPT DEFINITION 1990

ARCHITECTURE DEFINITION 1990

LABORATORY PROTOTYPE 1991

BRASS BOARD PROTOTYPE 1993

FLIGHT SYSTEM PROTOTYPE 1995

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
FLIGHT ELEMENTS
ADVANCED AVIONICS ARCHITECTURE

NOVEMBER 1989

TECHNOLOGY ISSUES:

INTERCONNECTION TOPOLOGY

THROUGHPUT OVERHEADS
- PARALLEL COMPUTATION
- INFORMATION TRANSFER
- FAULT TOLERANCE

SOFTWARE
- OPERATING SYSTEM
- REDUNDANCY MANAGEMENT

QUANTIFIABLE PERFORMANCE AND RELIABILITY

VALIDATION METHODOLOGY

LOW POWER/SMALL FEATURE SIZE/RADIATION HARDNESS

CANDIDATE PROGRAMS:

LUNAR/MARS INITIATIVE

NASP

FUTURE AUTONOMOUS SPACECRAFT

MAJOR ACCOMPLISHMENTS:

RECOGNITION OF THE NEED FOR SUCH SYSTEMS.

SIGNIFICANT MILESTONES:

91	92	93	94					R & D BASE
		93	94	95	96			ADV. DEVEL.
				95	96	97	98	FLIGHT SYSTEM

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
FLIGHT ELEMENTS
FAULT DETECTION AND FAULT MANAGEMENT

TECHNOLOGY CONCEPT:

Sensors
Reconfiguration
Design Knowledge Capture
Operations
Software

FAULT MANAGEMENT:
AN INTEGRATED APPROACH

FDIR
Diagnosis
Detection/Isolation
Hardware
Testability
Digraph Matrix Analysis
Performance

MAJOR OBJECTIVES:

- Monitoring, diagnosis, and reconfiguration at all system levels
- Unambiguous isolation of failures
- Integration with maintenance support and operations
- Optimize system operations to manage degraded system performance
- Lower development/operations costs
- Develop fault tolerant/FDIR requirements and specifications

KEY CONTACTS:

ARC - A. Patterson-Hine
JSC - J.T. Edge
LaRC - C. Meissner
MSFC - D. Weeks
KSC - T. Davis
JPL - D. Miller
HQ - G. Swietek (OSS), J. Di Battista (OAST)

Industry contacts: TBD

KEY FACILITIES:

JSC Testbeds
MSFC SSM/PMAD & ECLSS Testbeds
ARC Advanced Architectures Testbed

MAJOR MILESTONES:

- Review technology, investigate leveraging opportunities (1990)
- Define concept and develop integrated program technology development and integration plan(1990)
- Develop integrated testbed(s) (1992)
- Proof of concept demo (1993)

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
FLIGHT ELEMENTS
FAULT DETECTION AND FAULT MANAGEMENT

TECHNOLOGY ISSUES:

- Design accomodation of fault detection and fault management (FD/FM)
- Integrated program database support of FD/FM
- Design knowledge capture to support FD/FM
- Evolutionary, automated modeling techniques
- Scalability of current technologies
- Scope of human interface/interaction
- Software FD/FM
- Development of smart sensors and specialized processing functions with high reliability and lower power consumption
- Autonomous detection and recovery from faults
- Validation

CANDIDATE PROGRAMS:

- SSFP
- ALS
- Shuttle C
- Lunar/Mars missions

MAJOR ACCOMPLISHMENTS:

- Space Station Advanced Development Program already addressing some of the technology issues
- DARPA and ONR activities leveraged to some of the technology issues
- Basic testbeds already in place
- Core Technology Team available

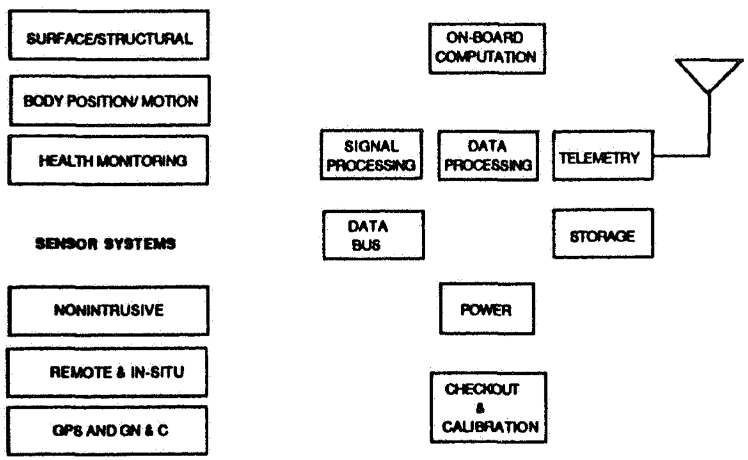
SIGNIFICANT MILESTONES:

R & D Base Integrated Program Plan	90 – 91
Integrated Design Strategies	92
Testbed Demonstrations	92
Proof of concept demonstration & optimization of system requirements document	93

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
FLIGHT ELEMENTS

ADVANCE SENSORS & INSTRUMENTATION

CONCEPT



MAJOR OBJECTIVES

LOW, WEIGHT, VOLUME, POWER & COST

	CURRENT CAPABILITY	NEW REQUIREMENTS
SENSORS - AIR DATA - TRANSITION - PRESSURE/TEMPERATURE INSTRUMENTATION NONINTRUSIVE AIR DATA		HIGH ACCURACY HIGH SPATIAL DENSITY HIGH FREQUENCY HIGH RELIABILITY
SMART DATA SYSTEMS		300Mb/sec
ON-BOARD PROCESSING		DATA COMPRESSION
ON-BOARD COMPUTATION		DATA PRODUCTS
ON-BOARD STORAGE		> TERABIT
DATA BUS		
CHECKOUT/CALS/AUTO RANGE		
POWER		
SOLID STATE LASERS		2 JOULE SOLID STATE
LIGHT WEIGHT OPTICS		
LG REFLECTORS/ANTENNAS		
SMART STRUCTURES/SERVOS		NDE
DETECTORS		
CRYOGENICS		20K COOLERS

KEY CONTACTS

LaRC	
GLEN TAYLOR	88-928-1733
BRUCE CONWAY	88-928-4755
DON LAWRENCE	88-928-5380
MSFC	
JOE ZIMMERMAN	88-824-3458
JSC	
PAUL SOLLOCK	88-525-8225
MIKE GAUDIANO (EH6)	88-525-8318
G.HARMON (EH6)	
K. DOUGLAS (LOCKHEED)	
K.PETERSON (NOVA SENSORS)	

FACILITIES

- CLEAN ROOMS
- ENVIRONMENTAL CHAMBERS
- THERMO VAC CHAMBERS
- CALIBRATION
- NDE LABS
- SENSOR LABS
- ENVIRONMENTAL
- R & QA
- MICROELECTRONIC/MATERIALS

- EMI/EMC
- CAD/CAE & ASIC
- LASER LAB
- DETECTOR LAB
- COMPUTATIONAL SUPPORT

ADVANCE SENSORS & INSTRUMENTATION

TECHNOLOGY ISSUES:

- O SMART SKINS - FIBEROPTIC TRANSDUCERS & TRANSMISSION LINES EMBEDDED IN ADVANCED COMPOSITES
- O MICRO-MACHINED TRANSDUCERS - EMPLOYING CLASSICAL SEMICONDUCTOR PROCESSING TECHNIQUES TO BUILD MECHANICAL STRUCTURES & TRANSDUCERS
- O SMART TRANSDUCERS - INTEGRATION OF A TRANSDUCER, SIGNAL CONDITIONERS, PROGRAMMABLE EMBEDDED MICROCONTROLLERS
- O ADVANCED INSTRUMENTATION - INTEGRATION OF SMART TRANSDUCERS INTO A DISTRIBUTED BUS OR FAULT TOLERANT LOCAL AREA NETWORK (LAN)
- O HYBRID ELECTRONICS & SURFACE MOUNT TECHNOLOGY
- O INTEGRATION OF DIVERSE TRANSDUCERS & SIGNAL TYPES INTO SMART TRANSDUCER MODULE
- O APPLICATION SPECIFIC INTEGRATED CIRCUIT (ASIC) DESIGN CAPABILITY TO MINIMIZE WEIGHT, POWER, & VOLUME PARAMETERS
- O SMART, MINIATURE & RELIABLE DATA ACQUISITION SYSTEMS (DAS)
- O ON BOARD DATA PROCESSING
- O ON BOARD COMPUTATION
- O ON BOARD STORAGE
- O ADVANCED DATA TRANSMISSION
- O LASER - BASED RENDEZVOUS SYSTEMS
- O 2 MICRON LASERS FOR EYE-SAFE AND WINDS
- O LIGHT WEIGHT OPTICS FOR WIND SHEAR LIDAR
- O CRYOGENICS : DEVELOP 20K COOLERS FOR SOLVING MOST DETECTOR PROBLEMS
- O LARGE REFLECTORS/ANTENNAS
- O INVESTIGATE & DEVELOP SENSORS FOR SMART STRUCTURES
- O DEVELOP MORE EFFECTIVE ELECTROMAGNETIC MEASUREMENT, MODELING, INJECTION & DETECTION SENSORS

CANDIDATE PROGRAMS:

UPGRADE OF ORBITER MODULAR AUXILIARY DATA SYSTEM (MADS)

UARS

EOS

SHUTTLE C

SPACE STATION FREEDOM

ELV

MISSION TO PLANET EARTH

MANNED MISSION TO MARS

LUNAR BASE

MAJOR ACCOMPLISHMENTS

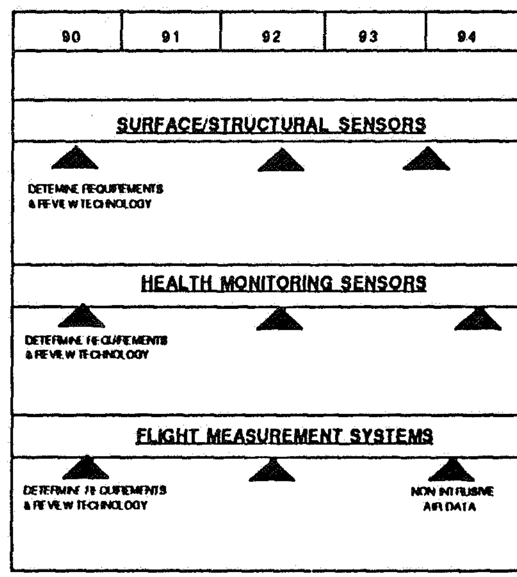
LIDAR

OPTICAL DISK

HIGH PRESSURE STAND ALONE PRESSURE MEASUREMENT DEVICE

ON-BOARD COMPUTING

SIGNIFICANT MILESTONES

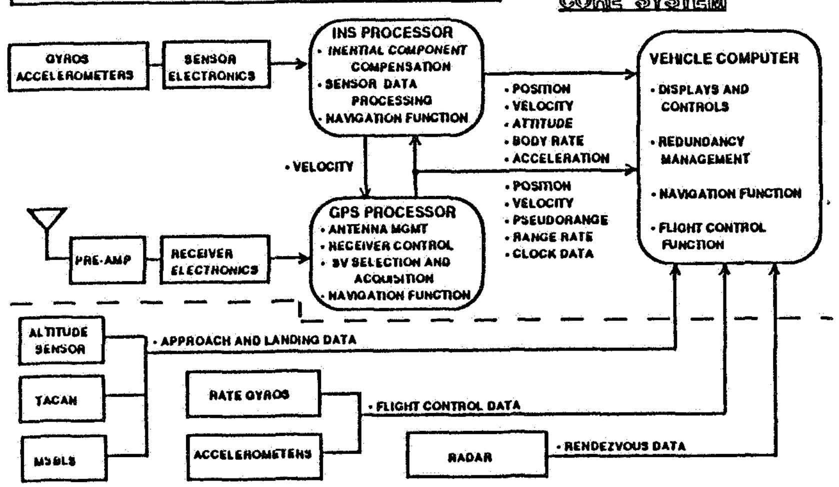


GOALS

- O SMART SENSORS
- O SMART SKINS
- O SMART, SMALL & RELIABLE DAS
- O ON BOARD DATA PROCESSING
- O ON BOARD COMPUTATION
- O ON BOARD STORAGE
- O ADVANCED DATA TRANSMISSION
- O SMART STRUCTURES
- O LASER APPLICATIONS
- O DETECTORS
- O NDE

INTEGRATED GPS/GN&C

INTEGRATED GPS/GN&C CONCEPT



MAJOR OBJECTIVES

- REDUCE MAINTENANCE COSTS
  REDUCED LRU COUNT
  HIGHER MTBF
- REDUCE WEIGHT, POWER, AND VOLUME
- AVOID OBSOLESCENCE OF DELETED SYSTEMS
- REDUCE VEHICLE LAUNCH AND TURNAROUND TIME
  TESTING - CALIBRATION - ALIGNMENT
- DEVELOP COMMON MODULAR SYSTEMS FOR MULTIPLE NASA APPLICATIONS
- PROVIDE AUTONOMOUS NAVIGATION CAPABILITY
  ASCENT - ORBIT - REENTRY
- PROVIDE AUTOLAND CAPABILITY
- REDUCE GROUND SUPPORT
- PROVIDE ATTITUDE DETERMINATION CAPABILITY
  ELIMINATE SENSORS THAT PROVIDE ATTITUDE UPDATE

KEY CONTACTS

PARTICIPANTS

TOM BARRY - NASA/JSC
JIM BLUCKER - NASA/JSC
MANNY FERNANDEZ - LITTON
HENDRIK GELDERLOOS - HONEYWELL
IRVING HIRSCH - BOEING AEROSPACE
PENNY SAUNDERS - NASA/JSC
AL ZEITLIN - ROCKWELL/STSD

SUPPLIERS

- AUTONETICS
- COLLINS
- HAMILTON STANDARD
- HONEYWELL
- LITTON
- MOTOROLA
- NORTHROP
- RAYTHEON
- SMITH INDUSTRIES
- TEXAS INSTRUMENTS

USERS

- BOEING (ALS; E-6; AOA; AIWS)
- MDAC (SPACE STATION)
- ROCKWELL (NSTS; NASP; GUNSHIP)
- NASA (NSTS; SPACE STATION; OMV; SHUTTLE C; EDO)
- ARMED SERVICES (VARIOUS AIRCRAFT APPLICATIONS)
- JOINT PROGRAM OFFICE (NASP)
- FAA
- DARPA (GPS GUIDANCE PACKAGE)

FACILITIES

- NASA JSC GPS LABORATORY
- AF GEOPHYSICS LABORATORY
- JET PROPOLUSION LABORATORY
- GPS JPO GPS STANDARD AND PRECISE POSITIONING SERVICE
- NASA AMES MOBILE DIFFERENTIAL GPS GROUND FACILITY
- OTHER GOVERNMENT AND CONTRACTOR FACILITIES

MAJOR MILESTONES

- STANDARD RLG INS AND GPS INTEGRATED SYSTEMS DELIVERED TO NAVY AND AIR FORCE
- INTEGRATED GPS/INS SYSTEMS DELIVERED FOR AF RC-135 AIRCRAFT
- INTEGRATED GPS/INS SYSTEM FOR REMOTELY PILOTED VEHICLE SUCCESSFULLY TESTED
- INS WITH EMBEDDED GPS RECEIVER IN PRODUCTION FOR CIVIL AVIATION (FOREIGN)
- HELICOPTER AND AIRCRAFT LANDING TESTS USING DIFFERENTIAL GPS SYSTEMS CONDUCTED BY NASA-AMES
- HIGH PRECISION ORBIT NAVIGATION FILTER (KALMAN) DEVELOPED BY NASA-JSC
- RELATIVE NAVIGATION CAPABILITY FOR RENDEZVOUS OPERATIONS INVOLVING TWO VEHICLES WITH GPS RECEIVERS EVALUATED BY NASA-JSC

INTEGRATED GPS/GN&C

TECHNOLOGY/APPLICATION ISSUES

- ACQUISITION OF TARGET VEHICLE DATA FOR AUTONOMOUS NAVIGATION DURING RENDEZVOUS, PROXIMITY, AND DOCKING OPERATIONS
  - COOPERATIVE TARGET
  - 'ANCHOR' SATELLITE
- VEHICLE ATTITUDE DETERMINATION USING GPS
  - ANTENNA SEPARATION LIMITED BY VEHICLE DIMENSIONS
- TRACKING SATELLITE VEHICLE SIGNAL THROUGH PLASMA
- MEETING AUTOLAND PERFORMANCE REQUIREMENTS
  - ACCURACY OF ALTITUDE DATA
- GPS UTLIZATION ABOVE 11,000 NM (e.g.; LUNAR MISSION RETURN)
  - REDUCED SATELLITE VEHICLE VISIBILITY

CANDIDATE PROGRAMS

- ASSURED SHUTTLE AVAILABILITY (ASA)
- SHUTTLE C
- EXTENDED DURATION ORBITER (EDO)
- ASSURED CREW RETURN VEHICLE (ACRV)
- SPACE STATION
- ORBITAL MANEUVERING VEHICLE
- ADVANCED LAUNCH STAGE
- ADVANCED UPPER STAGES
- NATIONAL AERO SPACE PLANE (NASP)
- LUNAR AND MARS MISSIONS RETURN

MAJOR ACCOMPLISHMENTS

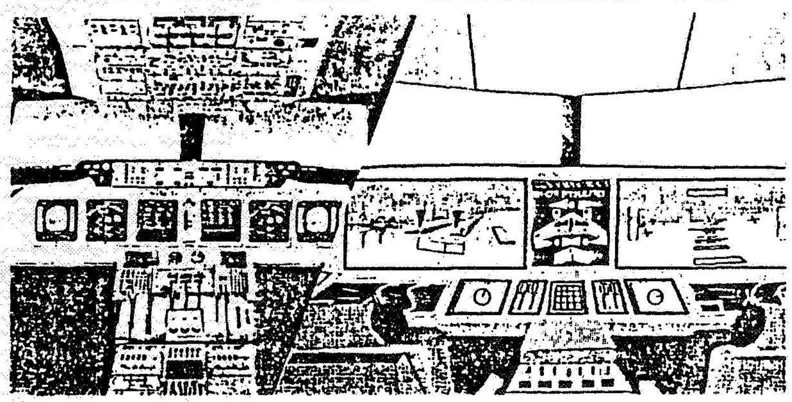
- F-15 FLIGHT TESTS DEMONSTRATE INERTIAL NAVIGATION ASSEMBLY CAPABILITY TO PROVIDE NAVIGATION AND FLIGHT CONTROL DATA - 1988
- INTEGRATED INS WITH EMBEDDED GPS FLOWN IN BOEING 767
  - FLIGHT TESTS PROGRAM - 1988
- FAA CERTIFICATION OF INS WITH EMBEDDED GPS - LATE 1990
- NATIONAL AERO SPACE PLANE SUBSYSTEM CONSORTIUM INVESTIGATING ANTENNA DESIGNS, ADVANCED ELECTRONICS, PLASMA TRANSMIT/RECEIVE LIMITATIONS
- SHUTTLE INTEGRATED GPS/GN&C CONCEPT AND FEASIBILITY STUDY
  - STUDY COMPLETE - 1990
  - FLIGHT DEMONSTRATION - 1993
- PRELIMINARY DESIGN STUDY OF INTEGRATED GPS & INS (MSFC)
  - INTEGRATED AND SEPARATE INS/GPS
  - MODULARIZED CONFIGURATION
- LABORATORY SIMULATIONS AND EVALUATIONS
  - ON-ORBIT OPERATIONS
  - AUTONOMOUS NAVIGATION
  - AUTOLAND

SIGNIFICANT MILESTONES

- IMPLEMENT STANDARD, MODULAR GPS RECEIVER
  - COST EFFECTIVE
  - SUPPORTS MULTIPLE PROGRAMS
  - CONFIGURABLE TO SPECIFIC APPLICATION
  - INCLUDE TESTABILITY AS DESIGN REQUIREMENT
- CONDUCT TRADE STUDY OF TECHNIQUES TO ACCOMPLISH AUTOLAND, INCLUDING A FLIGHT DEMONSTRATION
- CONDUCT TRADE STUDY OF TECHNIQUES TO PERFORM AUTONOMOUS NAVIGATION, BY MISSION PHASE, FOR VARIOUS TRANSPORTATION PROGRAMS
  - ASCENT - ORBIT - REENTRY
- CONDUCT TRADE STUDY OF TECHNIQUES FOR GPS DETERMINATION OF VEHICLE ATTITUDE, INCLUDING A FLIGHT DEMONSTRATION

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
FLIGHT ELEMENTS
ADVANCED DISPLAYS AND CONTROLS

ADVANCED DISPLAYS & CONTROLS CONCEPTS:



MD11 COCKPIT   ADVANCED COCKPIT TECHNOLOGY CONCEPT

MAJOR OBJECTIVES:

- LOWER COST, IMPROVED MAINTAINABILITY/RELIABILITY
- FOR SHUTTLE IN PARTICULAR, ELIMINATE PARTS/SKILLS OBSOLESCENCE
- REDUCED WEIGHT, VOLUME, AND POWER CONSUMPTION
- INHERENT GROWTH CAPABILITY FOR NEW FUNCTIONS OR ADVANCING TECHNOLOGY (I.E., PAYLOAD USER I/F)
- IMPROVEMENT IN PILOT'S SITUATIONAL AWARENESS
- REDUCTION IN PILOT'S/OPERATOR'S WORKLOAD
- IMPROVED FLIGHT SAFETY AND OPERATING EFFICIENCY
- COMMONALITY AND SOFTWARE RECONFIG. INTERFACE FOR FLEXIBILITY AND LOWER COST IN THE SUPPORT OF MULTIPLE PROGRAMS
- ELIMINATION OF PAPER/MANUAL CLUTTER THROUGH USE OF INTERACTIVE OPTICAL DISK TECHNOLOGY
- IMPROVED AUTONOMY THROUGH USE OF AI AND HUMAN-CENTERED AUTOMATION

KEY CONTACTS:

- DEAN KOCIAN/ WRIGHT R & D CENTER/ SUPERCOCKPIT PROGRAM
- DOC DOUGHERTY/ DARPA/ PILOT'S ASSOCIATE PROGRAM
- FRANK GOMER/ HONEYWELL/ PHEONIX RESEARCH CENTER
- GENE ADAM/ McDONNEL DOUGLAS/ 'BIG PICTURE' DISPLAY PROGRAM
- ANDREW FARKAS/ JOHNSON SPACE CENTER/ EF2
- DR. McGREEVY/ AMES RESEARCH CENTER/ AEROSPACE HUMAN FACTORS DIV.
- BILL RUCKS/ ROCKWELL STSD
- TERRY EMERSON/ WRIGHT R & D CENTER/ COCKPIT INTEGRATION DIRECTORATE

FACILITIES:

- JSC/ EF2 D & C PORTION OF ADV. SYSTEMS DEVELOPMENT LAB
- JSC/ SHUTTLE ENGINEERING SIMULATOR
- LaRC/ ADV. CONCEPTS SIMULATOR & CREW STATION SYSTEMS RESEARCH LAB
- LaRC/ TRANSPORT SYSTEMS RESEARCH VEHICLE (AFT FLT. DECK W/COLOR DISPLAYS)
- ARC/ MAN VEHICLE SYSTEMS RESEARCH FACILITY & FLIGHT SIMULATION COMPLEX
- WRIGHT R & D CENTER/ SUPERCOCKPIT LAB & 'MAGIC' COCKPIT FACILITY

MAJOR MILESTONES (1990 - 1995):

• SIGNIFICANT IMPROVEMENTS IN FLAT-PANEL TECHNOLOGIES	
— FULL-COLOR, SUNLIGHT-LEGIBLE LIQUID CRYSTAL DISPLAYS	FY 90-91
— FULL-COLOR PLASMA PANEL (15-IN. DIAG.), PHASE II SBIR	FY 91-92
• FLIGHT-WORTHY GRAPHICS GENERATORS CAPABLE OF REAL-WORLD 3-D PICTORIAL DISPLAYS	FY 91-92
• IMPROVEMENTS IN VOICE, TOUCH, AND HAND-CONTROLLER INPUT TECHNOLOGIES	FY 91-92
• FINALIZED SPACE STATION MULTI-PURPOSE APPLICATIONS CONSOLE DESIGN	FY 91-92
• RESULTS OF AIR FORCE SUPERCOCKPIT AND BIG PICTURE PROGRAMS	FY 92-93
• RESULTS OF DARPA PILOT'S ASSOCIATE AND HDTV STUDIES	FY 93-94
• RESULTS OF NASA AIRCRAFT SAFETY/AUTOMATION PROGRAM	FY 93-94
• ORBITER GLASS COCKPIT DISPLAY UPGRADE	FY 93-95

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SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
FLIGHT ELEMENTS
ADVANCED DISPLAYS AND CONTROLS

TECHNOLOGY ISSUES:

- ORBITER DOWN-TIME FOR HARDWARE INSTALLATION
- MATURITY OF FLAT-PANEL DISPLAY TECHNOLOGY
- DANGER OF MAKING CREW BORED/MACHINE MINDERS
- ADVANCED DISPLAY SYMBOLOGY/PICTORIAL FORMATS
- MATURITY AND UTILIZATION OF AI TECHNOLOGY
- GROWTH AND FLEXIBILITY
- INTERACTIVE DISPLAY/CONTROL NEEDS MORE RESEARCH
- IMPACT OF ELECTRONIC DISPLAYS & CONTROLS (ALL-GLASS COCKPIT) ON CREW TRAINING

CANDIDATE PROGRAMS:

- SPACE SHUTTLE (ASSURED SHUTTLE AVAILABILITY)
- SPACE STATION MPAC
- NATIONAL AERO-SPACE PLANE
- COMBINED AFT MANIPULATOR WORKSTATION (ORBITER)
- AVIATION SAFETY/AUTOMATION
- ADVANCED COCKPIT/FLIGHT MANAGEMENT TECHNOLOGY (PROPOSED FY 92 NEW INITIATIVE IN AERO)

MAJOR ACCOMPLISHMENTS:

- EMERGENCE OF SEVERAL GLASS COCKPITS IN MILITARY AND COMMERCIAL AIRCRAFT (747-400, GULFSTREAM G IV, MD11, F-15E, AND BEECH STARSHIP)
- EMERGENCE OF COLOR ACTIVE-MATRIX LCD TECHNOLOGY
- EMERGENCE OF HIGH-DEFINITION TV (HDTV) TECHNOLOGY
- EMERGENCE OF REAL-TIME GRAPHICS DISPLAY TECHNOLOGY
- EMERGENCE CONTINUOUS-SPEACH, SPEAKER-INDEPENDENT VOICE RECOGNITION TECHNOLOGY

SIGNIFICANT MILESTONES:

• SPACE STATION PERMANENT MANNED CAPABILITY, MPAC	1995-96
• CREW EMERGENCY RETURN VEHICLE	1997
• MANNED LUNAR MISSION	2001
• MANNED MARS MISSION	2016
• ORBITER BLOCK II COCKPIT	- - - -

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
FLIGHT ELEMENTS
ADVANCED COMMUNICATIONS AND TELEMETRY

NOVEMBER 1989

ADVANCED TECHNOLOGY :

1. GALLIUM ARSENIDE VHSIC
2. FIBER OPTICS
3. ADVANCED ANTENNA DESIGN
4. FREE SPACE OPTICAL COMMUNICATION
5. ADVANCED SIGNAL PROCESSING
6. ADVANCED MODEM / CODEC DEVELOPMENT

MAJOR OBJECTIVES:

. UTILIZE NEW SPECTRUM
. MAXIMIZE DATA RATE THROUGH AVAILABLE SPECTRUM
. PROVIDE FLEXIBLE WIDEBAND DATA DISTRIBUTION NETWORKS (DDNs)
. VERY LOW POWER CONSUMPTION
. DENSE PACKAGING
. RFI/EMI IMMUNITY
. GRACEFUL DEGRADATION
. MULTIBEAM ANTENNAS

KEY CONTACTS:

JSC/ K. LAND
LeRC/ R. LEONARD, J. HARROLD
GSFC/ M. FITZMAURICE, D. DALTON
NMSU/ F. CARDEN, S. HORAN

KEY FACILITIES:

JSC- C&T ENGIINEERING LAB.
LeRC: MMW TEST FACILITY; DSP LAB.
GSFC: LASER COM. LAB.
NMSU- CENTER FOR SPACE TELEM. & TELECOM. SYSTEMS

MAJOR MILESTONES:

DARPA MIMIC PHASE I (MAY'89), PHASE II (1991-94)

EVOLUTION OF STANDARDS
- FDDI STANDARD

ACTS COM SYSTEM
32 GHz TWTA 7W 1992, 50W 1995

"COMMON" SIGNAL PROCESSOR (CSP, GSP, EMSP, GASP)

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
FLIGHT ELEMENTS
ADVANCED COMMUNICATIONS AND TELEMETRY

NOVEMBER 1989

TECHNOLOGY ISSUES:

1. PRODUCIBILITY OF GaAS
2. POWER LIMITS ON DISTRIBUTION
3. PACKAGING @ HIGH (> 20 GHz)
4. POINTING ACCURACY/ STABILITY
5. SOFTWARE DEVELOPMENT
6. SOFTWARE DEVELOPMENT

CANDIDATE PROGRAMS:

- SPACE STATION
- STS UPGRADES
- LUNAR MARS EXPLORATIONS
- ATDRSS

MAJOR ACCOMPLISHMENTS:

- 32GHz PHASED ARRAY UNDER DEVELOPMENT
- Gbps FIBER OPTICS LINKS IN LABORATORY TEST
- VHSIC PHASE I CHIPS AVAILABLE

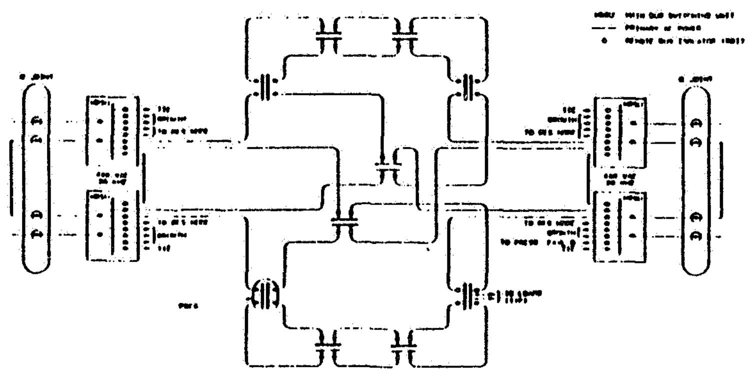
SIGNIFICANT MILESTONES:

- SMALLER, LIGHTER, LOWER POWER PACKAGING
- IMPROVED RELIABILITY
- STANDARDIZATION OF INTERFACES

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
FLIGHT ELEMENTS
ADVANCED ELECTRICAL POWER, DISTRIBUTION AND CONTROL

NOVEMBER 1989

ADVANCED ELECTRICAL POWER, DISTRIBUTION AND CONTROL



SPACE STATION RING DISTRIBUTION SYSTEM (EXTERNAL LOAD AREAS ONLY)

MAJOR OBJECTIVES:

- REDUCE COSTS TO LEO, LUNAR/MARS SURFACE
- REDUCE WEIGHT
- INCREASE AVAILABLE POWER/ENERGY
- IMPROVED REDUNDANCY MANAGEMENT
- IMPROVED POWER QUALITY, USER AVAILABILITY
- FAULT TOLERANT, INTEGRATED BITE

KEY CONTACTS:

H. BRANDHORST/LeRC
I. HANSEN/LeRC
J. MILDICE/GDSS
J. BIESS/TRW
R. BECHTEL/MSFC

FACILITIES:

LeRC POWER TECHNOLOGY TESTBED

MAJOR MILESTONES (1990-1995):

SPACE STATION FREEDOM

1990 ADV. DEV. TEST BED DEMOS

ADVANCED LAUNCH SYSTEM

1990 — 1992 ADV. DEV. DEMO OF IEPS

CIVIL AERO-FBL/PBW

1991 — 1993 TECH. VALID. | 1995 DDT&E | 1996 FLIGHT DEMO.

LUNAR/MARS INITIATIVE

1992 — 1995

STUDIES ---------- ADV. DEV. PROG.

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
FLIGHT ELEMENTS
ADVANCED ELECTRICAL POWER, DISTRIBUTION AND CONTROL

NOVEMBER 1989

TECHNOLOGY ISSUES:

END-TO-END EPS MANAGEMENT WITH FAULT LIMITING, RECOVERY AND FAIL SAFE/FAIL OPERATIONAL RECONFIGURATION

DISTRIBUTED vs. DEDICATED PMAD FOR REDUNDANCY, RELIABILITY, OPERABILITY

BITE INTEGRATED INTO DESIGN AT MANUFACTURE

ASA: DDT&E FOR ELECTRICAL ACTUATORS RETROFIT BY INSPECTION DATE

CANDIDATE PROGRAMS:

ADVANCED LAUNCH SYSTEM

ASSURED SHUTTLE AVAILABILITY

CIVIL AERO - POWER-BY-WIRE/FLY-BY-LIGHT

LUNAR/MARS INITIATIVE

AF/WRDC - MORE ELECTRIC AIRPLANE - RETROFIT F-16

DAVID TAYLOR SHIP R&DC - ELECTRONIC NAVY

MAJOR ACCOMPLISHMENTS:

- DEMONSTRATED MULTI-REDUNDANT, FAULT TOLERANT, MICROPROCESSOR CONTROLLED SSF 20 kHz ELECTRICAL POWER DISTRIBUTION SYSTEM
- DEMONSTRATED VARIABLE SPEED DRIVES TO 200 HP, ELECTRICAL ACTUATORS TO 25 HP/DESIGNS TO 75 HP

SIGNIFICANT MILESTONES:

1990 R&T BASE - COMPS, POWER SEMI'S

1991 1992 ADV. DEV. - SSF, ALS

1995 DDT&E

▽ LEV. 5 MATURITY

△ NSTS NEED DATE

△ LUNAR/MARS NEED DATE

VALIDATION NEAR COMPLETE:

- ADVANCED HIGH POWER PMAD CONCEPTS APPLICABLE TO CANDIDATE PROGRAMS
- ADVANCED MOTOR CONTROL ENABLING INDUCTION MOTOR EXPLOITATION FOR LUNAR/MARS VEHICLES

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
FLIGHT ELEMENTS
EMA/POWER SYSTEMS

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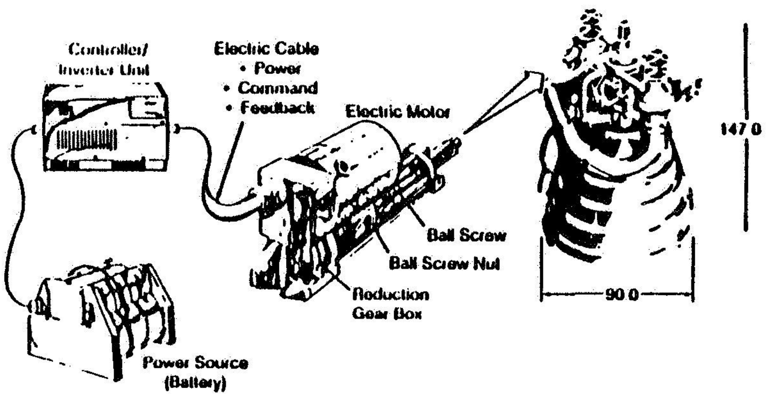
EMA/POWER SYSTEMS



MAJOR OBJECTIVES:

REDUCE KSC TURN AROUND COSTS ; INCREASE LAUNCH RATE
- ELIMINATE EXCESSIVE MAN TESTS AND VERIFICATIONS
- ADD SELF CHECKOUT THROUGH BUILT-IN-TEST (BITE)
- ELIMINATE GROUND SUPPORT CARTS AND EQUIPMENT

IMPROVE REDUNDANCY, RELIABILITY AND DECREASE WEIGHT
- MATCH FLIGHT CONTROLS, POWER SOURCE, ACTUATORS
- USE DEMAND DRIVEN SYSTEM - SIMPLE IMPLEMENTATION

IMPROVE DISPATCH RELIABILITY
- AUTOMATED VEHICLE CHECKOUT
- LOW STANDBY POWER/ENERGY
- ELIMINATE HYDRAULIC SILTING

REDUCE STANDDOWN TIME

TECHNOLOGY TRANSFER TO CIVIL SECTOR

KEY CONTACTS:

G. SUNDBERG/LeRC
J. T. EDGE/JSC
C. CORNELIUS/MSFC
C. McCLESKEY/KSC
B. LUM/RI-DOWNEY
S. TAQUI/GDSS
J. ANDERSON/BAC

FACILITIES:

MSFC ACTUATOR TEST FACILITY
ROCKWELL-DOWNEY
AIRFORCE WRDC-FLIGHT DYNAMICS

MAJOR MILESTONES (1990-1995):

ASSURED SHUTTLE AVAILABILITY (ASA)

1990 TECHNOLOGY, RISK, COST ASSESSMENT

ADVANCED LAUNCH SYSTEM

▽ EMA DESIGNS ▽ COMPLETE DEMOS/ COST/OPERABILITY ▽ IOC

1990 | 1991 | 1992 | … | 2000

CIVIL AERO-FBL/PBW

▽ VALID. STUDIES REVIEW TECH. DDT&E ▽ FLIGHT DEMO. ▽

1991 | 1992 | 1993 | 1994 | 1995 | 1996

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SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
FLIGHT ELEMENTS
EMA/POWER SYSTEMS

NOVEMBER 1989

TECHNOLOGY ISSUES:

ASA: DDT&E FOR EMA RETROFIT BY INSPECT. DATE

END-TO-END EPS MANAGEMENT WITH FAULT LIMITING, RECOVERY AND FAIL SAFE/FAIL OPERATIONAL RECONFIGURATION

DISTRIBUTED vs. DEDICATED PMAD FOR REDUNDANCY, RELIABILITY, OPERABILITY

BITE INTEGRATED INTO DESIGN AT MANUFACTURE

CANDIDATE PROGRAMS:

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ASSURED SHUTTLE AVAILABILITY

CIVIL AERO - POWER-BY-WIRE/FLY-BY-LIGHT

LUNAR/MARS INITIATIVE

AF/WRDC - MORE ELECTRIC AIRPLANE - RETROFIT F-16

DAVID TAYLOR SHIP R&DC - ELECTRONIC NAVY

MAJOR ACCOMPLISHMENTS:

- PRELIMINARY ASA STUDIES COMPLETED
- KSC TURNAROUND FLOW ANALYSIS INITIATED
- TECHNOLOGY DEMOS/ASSESSMENT INITIATED
- DEMONSTRATED ELECTRIC ACTUATORS/ DRIVES TO 25 HP/DESIGNS TO 75 HP
- DEMONSTRATED MULTI-REDUNDANT, FAULT TOLERANT, MICROPROCESSOR CONTROLLED SSF 20 kHz ELECTRICAL POWER DISTRIBUTION SYSTEM

SIGNIFICANT MILESTONES:

1990 R&T BASE - COMPS, POWER SEMI'S

1991 1992 ADV. DEV. - SSF, ALS

1995 DDT&E

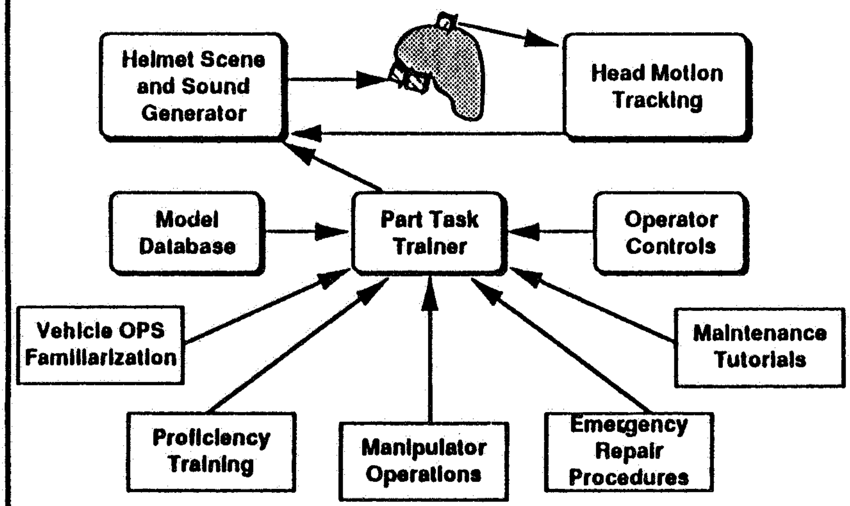
▽ LEV. 5 MATURITY △ NSTS NEED DATE △ LUNAR/MARS NEED DATE

VALIDATION NEAR COMPLETE:

- ADVANCED HIGH POWER PMAD CONCEPTS APPLICABLE TO CANDIDATE PROGRAMS
- ADVANCED MOTOR CONTROL ENABLING INDUCTION MOTOR EXPLOITATION

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
FLIGHT ELEMENTS
IN - FLIGHT CREW TRAINING

IN - FLIGHT CREW TRAINING



MAJOR OBJECTIVES:

- Provide more effective training environments
  - Video or animated task descriptions
  - Interactive training environments
    - •• Computer generated, synthetic 3-D training scenarios
    - •• Active computer control of hand input devices during scene playback for tactile training
- Provide accelerated in-flight training capability
  - Refresh crew skills
  - Practice unplanned contingency operations in a realistic environment
- Enhance crew preparedness
- Enhance crew safety

KEY CONTACTS:

C. Goit / JSC / FM8

P. Galicki / JSC / FM8

S. Murray / JSC / VG3

FACILITIES:

- Integrated Graphics Operations Analysis Laboratory (IGOAL)
  - RMS MIL Simulators: Shuttle, SSF
  - Proximity Operations Simulators: Shuttle, Shuttle-C, OMV, MMU
- JSC Systems Engineering Simulator

MAJOR MILESTONES (1990 - 1995)

- Test and evaluate faster machines with graphics capability
- Test simulation interaction with current hardware
- Develop non-realtime system with dynamics and collision detection on current hardware
- Test and evaluate stereo graphics hardware
- Investigate malfunction training concepts to establish viability

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM
FLIGHT ELEMENTS
IN - FLIGHT CREW TRAINING

TECHNOLOGY ISSUES:

- Integration with existing flight systems
- Display and processor capabilities
  - Low weight, volume and power requirements
  - Provide for multiple trainees interacting within a realistic synthetic 3-D training scenario
  - Allow local storage of "digital" tapes of training scenarios
  - Facilities to upload from remote training library

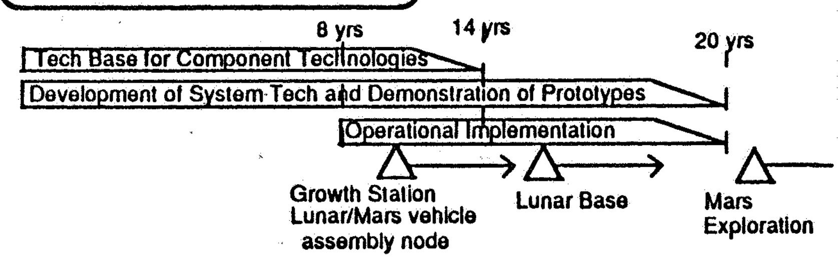
CANDIDATE PROGRAMS:

- Space Station Freedom (SSF)
  - Remote Manipulator Systems (SRMS, SSRMS)
  - Flight Telerobotic Servicer (FTS)
  - Orbital Maneuvering Vehicle (OMV) Piloting
  - Shuttle Piloting and Landing
- Space Shuttle
  - Remote Manipulator System
  - Proximity Operations
  - Approach and Landing

MAJOR ACCOMPLISHMENTS:

- Development of kinematic and dynamic simulators for generic remote manipulator systems
- Teleoperated systems technology investigations
  - Helmet mounted display
  - Stereoscopic vision systems
- Man-in-the-loop simulator development
  - Manipulator Simulations: SRMS, SSRMS, FTS
  - Spacecraft Simulators: Shuttle, OMV
- RMS Partial Task Trainer hosted on Silicon Graphics IRIS 4D/70GT
  - Kinematic simulation with near real-time performance using low fidelity models
  - RMS control panel and hand controllers

SIGNIFICANT MILESTONES:



- Identify appropriate training tasks
- Determine system requirements
- Define system architecture
- Develop and integrate system hardware
- Develop training software for prototype system
- Flight demonstration of training capabilities
- Operational trainer development
- Training plan implementation

TECHNOLOGY HOLES

o Modular S/W & H/W

o Mathematical formulation

o Long life reliable operation on-demand (inert or operational)

o Validation methodology & tools (H/W & S/W)

o Expert systems validation

o Up-front requirements definition

o GPS use abose 11 kn-m and during aerobraking

o Antiquated technology replacement & down time (AAS)

o Selection of communication approach for SSF prox. ops.

o High data raate transmission to ground capability

o Isolation/pointing/stabilization for optical communications

o Total system integration & validation

o Interconnect test beds across country

o R&T and ADP funding inadequate to facilitate timely developments

CULTURAL CHANGES

- o All-weather launch capability and utilization
- o Launch with onboard defects/failures
- o Integration of flight systems and operations
- o Planning across multiple programs
- o Near-term user & technology insertion
- o Program selling minimizes use of technology
- o Trade information not data
- o Validation of only changes not total S/W package
- o Utilize commercial & other sectors for technology (eliminate NIH)
- o Paperless management
- o Reduction of standing ops armies

MAJOR DEMONSTRATIONS

o Fault tolerant avionics architecture for ALS - 5/90

o Fiber optics bus (lab demo) - 4 Gbits transmission

o Power system autonomy - 1990

o EMA (25-75 HP) demo for ALS - 1992

o Next-generation orbiter experimental cockpit facility needed

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PRESENTATION 4.3

N91-17057

PAYLOAD ACCOMMODATIONS

AVIONICS NEEDS	CURRENT TECH	HOLES
USER ORIENTED - Be Able to Talk to Their P/L - Get Better Onboard Data Storage - Obtain Vehicle Data (Vector & Attitude) - Video Services		
REDUCE PAYLOAD CREW DEPENDENCE		AUTO ROBOTICS EXPERT SYSTMS VOICE RECOGNOTION COMPUTERS
AUTONOMOUS RENDERVOUS & DOCKING	SENSORS - OPTICAL & LASER DOCKING - OMV - DOCKING & GRAPPLING MECHANISMS	BETTER SENSORS - RELATIVE NAVIGATION - ROBOTIC VISION
STANDARDIZATION OF DATA FORMATS & INTERFACES	SATELLITE COMM GROUND STATIONS	
ENCRYPTION		
ONBOARD COMPUTER PROCESSING CAPABILITY		

AVIONICS NEEDS	CURRENT TECH	HOLES
USER FRIENDLY SYSTEM		
INCREASE MEMORY CAPACITY/ DATA STORAGE MEDIUM		
INCREASE FAULT TOLERANCE		
INCREASE RELIABILITY		
NEED AUTOMATION		
MANIPULATOR CONTROL		
PAYLOAD NAVIGATION		

GENERAL OBSERVATIONS

- NEED DIRECT INVOLVEMENT FROM PAYLOAD/USERS (I.E. SATELLITE, UTILIZATION OFFICES)
  - PAYLOAD ACCOMMODATIONS "NEEDS" IDENTIFIED

- CONCERN WITH BUDGET SHORTFALL
  - ELIMINATION OF CAPABILITIES AND GROWTH MARGINS FOR PAYLOAD USERS

FINDINGS

- INCREASE OPS EFFICIENCY FOR PAYLOAD SERVICES
  - USE OF COMMERCIAL/INDUSTRY/DOD STANDARD
  - USE OF AUTOMATION AND EXPERT SYSTEMS
  - SEPARATION OF HOST VEHICLE & P/L ACCOMMODATIONS TO THE EXTENT PRACTICAL
  - STANDARDIZE SET OF ROBUST SERVICES
  - MODULAR DESIGN TO ACCOMMODATE GROWTH AND UPGRADES

FINDINGS (CONT'D)

- NEED FOR INCREASED SAFETY
  - ADVANCED ONBOARD AVIONICS SOFTWARE TO ENHANCE ABORT CAPABILITY FOR PAYLOAD RETURN
  - AUTONOMOUS RENDEZVOUS AND DOCKING ALLOWS LOCAL CONTROL OF TIME CRITICAL OPERATIONS OF UNMANNED VEHICLE

NEEDS	HOLES
ENHANCING MANNED OPERATIONS OF PAYLOADS	LACK OF TECHNOLOGICAL MATURITY IN: – RELIABLE VOICE CONTROL – ROBOTIC VISION – ENHANCED DISPLAY SYSTEMS – PATH-PLANNING/COLLISION AVOIDANCE FOR VEHICLE AND MANIPULATOR – MULTIPLE VEHICLE MANIPULATOR CONTROL

"NEEDS"	"HOLES"
ULTRA RELIABLE MANRATED SOFTWARE	VERIFICATION OF SELF ADAPTIVE SOFTWARE
ENHANCING UNMANNED, ONBOARD OPERATIONS FOR PAYLOADS	IMMATURE TECHNOLOGY IN SENSORS/SYSTEMS – RELATIVE NAVIGATION – ROBOTIC VISION – PATH PLANNING AND COLLISION AVOIDANCE FOR VEHICLES AND MANIPULATORS

"NEEDS"	"HOLES"
RELIABLE/AVAILABLE MANIPULATOR	FAULT TOLERANT SYSTEM
ENHANCE DATA COMMUNICATION CAPABILITY FOR PAYLOAD	LACK OF DEFINED REQUIREMENTS
INCREASE ONBOARD DATA STORAGE	CAPABILITY FOR LONGTERM – 10^{12} – SPACE HARDENING – FAST RANDOM ACCESS

SUMMARY/RECOMMENDATIONS

- CURSORY LOOK ACROSS PAYLOAD ACCOMMODATIONS SUBJECTS
- TOPICS RECOMMENDED FOR NEXT PAYLOAD ACCOMMODATIONS MEETING
  - SPACE BASE TRANSFER VEHICLES
  - USER NEEDS
  - FOCUS ON SPECIFICS
- SYSTEMS ENGINEERING EFFORT REQUIRED
  - COORDINATE DISCIPLINES AND PROGRAMS (VEHICLE/PAYLOADS)
  - FOCUS TECHNOLOGY PLAN ACROSS ALL PROGRAMS
  - DEVELOP COMMONALITY ACROSS ALL PAYLOADS

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N91-17058

SYSTEMS ENGINEERING & INTEGRATION (SE&I)

SE&I SUMMARY

REQUIREMENTS

- MUST DEVELOP BETTER METHODS FOR DEFINING TOTAL SET OF NEEDS ALSO REQUIREMENTS FOR MULTIPLE SET OF PROGRAMS
  - CREATE TRUE CHIEF ENGINEERS OFFICE AT HDQTRS
  - DO SE&I ACROSS ALL PROGRAMS
  - ESTABLISH PRIORITY OF NEEDS TO MAXIMIZE USE OF TECHNOLOGY

- NASA SHOULD REQUIRE DEMONSTRATION OF FUNCTIONAL EQUIVALENT OF FINAL PRODUCT DURING PHASE B
  - MOVE PRR FROM PHASE C/D TO PHASE B

SE&I SUMMARY

- SE&I MUST BE RECOGNIZED AS THE TOTAL INFRASTRUCTURE THAT IS ESTABLISHED TO CONTROL METHODS, POLICIES, AND PROCEDURES FOR PRESENT AND FUTURE NASA PROGRAMS
- INCLUDES THE DEVELOPMENT OF GENERIC TOOLS NECESSARY TO SUPPORT AND ENFORCE THE METHODS, POLICIES, AND PROCEDURES DEFINED FOR SPECIFIC PROGRAMS

SE&I SUMMARY (CON'T)

RISK/REDUNDANCY

- DEVELOP BACKBONE OF ANALYSIS CAPABILITY FOR RISK MANAGEMENT IN FORM OF EASY TO USE TOOLS THAT CAN BE TAILORED BY EACH PROJECT TO ITS SPECIFIC NEEDS I.E., SPREAD SHEET FORMAT THAT EACH PROJECT FILLS IN THE DATA

- REDUNDANCY/FAULT TOLERANCE MANAGEMENT MUST BE PART OF GENERIC SE&I TOOL SET AND NOT UNIQUE TO EACH PROJECT. DOES NOT MEAN THAT SOME PROGRAM SPECIFIC TAILORING NOT DONE, BUT GENERAL GUIDELINES FOR ALL PROGRAMS

SE&I SUMMARY (CON'T)

STANDARDS

- NASA AND SE&I MUST TAKE ACTIVE LEADING ROLE IN STANDARDS COMMITTEES (AIAA, IEEE, ETC). TAKE STRONG ROLE IN DIRECTING INDUSTRY TO ESTABLISH STANDARDS THAT BENEFIT NASA

- ESTABLISH A NASA/AEROSPACE INDUSTRY WORKING GROUP TO DEFINE INTERFACE STANDARD BETWEEN NASA LABS AND INDUSTRY TO ALLOW SHARING OF DATA, MODELS, ETC. FORCE SOME LEVEL OF COMMONALITY BETWEEN NASA CENTERS

SE&I SUMMARY (CON'T)

COST

- NASA HAS HISTORY OF UNDERESTIMATING COST OF PROJECTS
  - BEGINS DROPPING FEATURES IN DDT&E THAT COST IN OPS
  - BUT OVER ESTIMATING BECOMES SELF-FULFILLING PROPHECY AND WE WILL SPEND WHATEVER WE PREDICT

- NASA MUST COME UP WITH INCENTIVE FOR CONTRACTORS TO AGREE WITH REUSE CONCEPTS. NO REASON FOR CONTRACTOR TO PROPOSE REUSE OF HARDWARE OR SOFTWARE
  - NO PROCEDURES/POLICY WITHIN NASA
  - NO GUIDELINES OF CONFIGURATION CONTROL
  - NO GUIDELINES FOR QUALITY MANAGEMENT

- NASA NEEDS TO FORMALLY ADOPT TQM
  - ESTABLISH SHORT TERM (1 YEAR) PRODUCTS/BENEFITS
  - DEMONSTRATE RESULTS
  - DEFINE MID/LONG TERM (3&7) GOALS

SE&I SUMMARY (CON'T)

TESTBED

- CONSIDER CONCEPT OF "NASA NATIONAL TEST BED" BUT DO NOT RESTRICT CONCEPT TO SINGLE CENTER OR LOCATION. CREATE COMPLIMENTARY SET OF INTERCONNECTED LABS BASED ON FUNCTION AND EXPERTISE OF EACH INDIVIDUAL CENTER
  - RECOGNIZE LABS ARE FOR BENEFIT OF INDIVIDUALS RESPONSIBLE FOR SUBSYSTEMS IN ADDITION TO ESTABLISHING CONFIDENCE FOR PROGRAM MANAGEMENT
- MUST CREATE POLICY AND TOOLS FOR TESTABILITY ACROSS PROJECTS

SE&I SUMMARY (CON'T)

OPERATIONS

- NO CHECK AND BALANCE SYSTEM FOR NASA OPERATIONS PHASE. SINCE NASA IS THE BUYER, DEVELOPER, AND USER WE HAVE NO MECHANISM OR INCENTIVE TO REDUCE COSTS.

- THERE MUST BE A CULTURAL CHANGE AT NASA FROM ADMINISTRATOR DOWN THAT FORCES TECHNOLOGY INSERTION INTO PROJECTS THAT RESULTS IN COST/EFFICIENCY BENEFITS PER PROJECT EVEN IF IT MOVES THE FUNDS TO ANOTHER PROGRAM.

SE&I SUMMARY (CON'T)

TOPICS

- DEFINITION
- REQUIREMENTS
- COST

RISK/REDUNDANCY MGMT

- STANDARDS
- TESTBED
- OPERATIONS

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15. Supplementary Notes

16. Abstract

The Space Transportation Avionics Technology Symposium was held in Williamsburg, VA., November 7-9, 1989. The focus of the symposium was to examine existing and planned avionics technology processes and products and to recommend necessary changes for strengthening priorities and program emphases. Innovative changes in avionics technology development and design processes, identified during the symposium, are needed to support the increasingly complex, multi-vehicle, integrated, autonomous space-based systems. Key technology advances make such a major initiative viable at this time: digital processing capabilities, integrated on-board test/checkout methods, easily reconfigurable laboratories, and software design and production techniques.

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